MISSOURI
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"…identifying, designating, managing and restoring the best remaining examples of natural communities and geological sites encompassing the full spectrum of Missouri's natural heritage"

Editor's Note

Missouri's Big River Systems

The Great Missouri and Mississippi River flood of 1993 remains a seminal event in our state's and the country's history. Beginning in April 1992, above-average rainfall and below-average temperatures resulted in above normal soil moisture and reservoir levels in the Missouri and Mississippi River basins into 1993. In winter 1992–93, the Midwest experienced heavy snowfall, followed by daily one-to-two-inch rains in June and July across northern and central Missouri. Soils in central and northern Missouri were already saturated by June 1. Storms, persistent and repetitive in nature during the late spring and summer, bombarded the Upper Midwest with voluminous rainfall. In one night in July 1993, central Missouri received four to nine inches (locally as high as 18 inches) of rain causing a major river surge in late July. Flood levels topped 20 feet at the levee protecting Chesterfield and Earth City but the levee (built under much controversy in response to the 1844 flood) held with just over two feet to spare. However, portions of Jefferson City flooded, with flood waters blocking off traffic from Highways 54 and 63. In Alton, Illinois only

A quiet sunset moment on the Missouri River at Boonville.

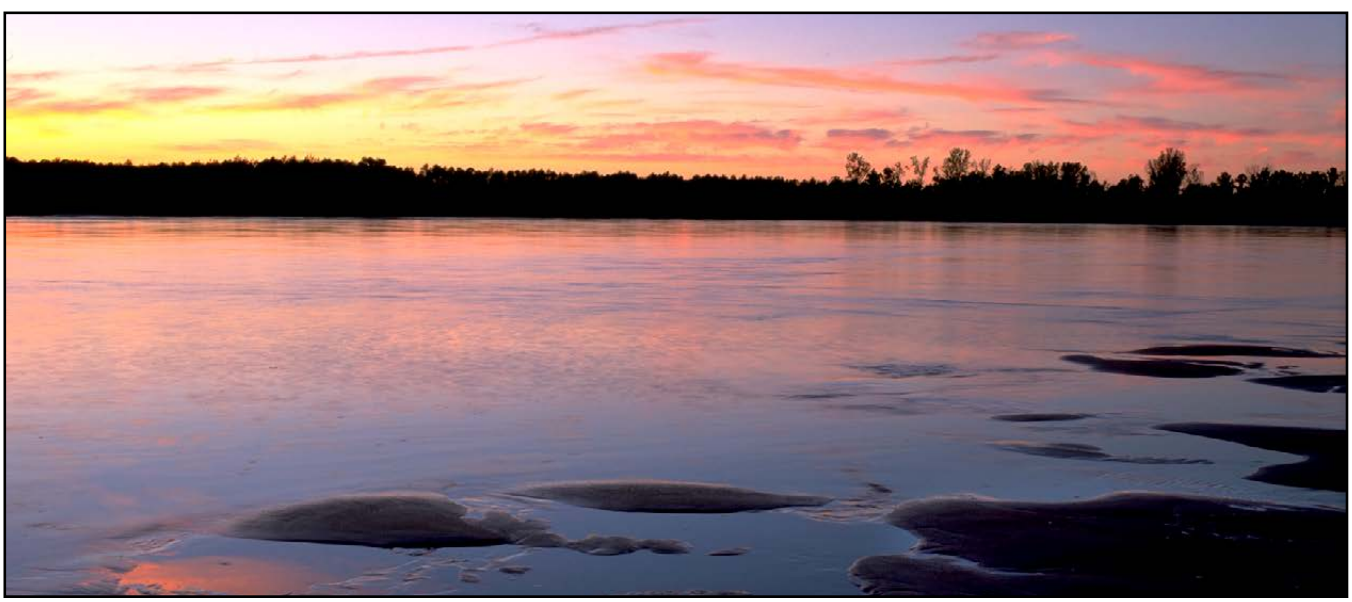

Photo by Pat Whalen, Missouri Department of Conservation

rooftops were visible from aerial surveys, and in Quincy, Illinois the farm fields witnessed white-cap flood waters. The 1993 flood broke record river levels set during the 1973 Mississippi and the 1951 Missouri river floods. Flood damage losses were 15 billion dollars (estimated at 27 billion dollars in 2021) almost exceeding the damage caused by the historic 1927 Great Flood of the lower Mississippi. The damages of the 1993 flood devastated many communities, while the 1927 flood remains the costliest big river flood event in the history of the United States regarding property damage and human displacement.

This issue of the *Missouri Natural Areas Newsletter* will examine not only the historic wetlands and the condition of big river hydrology, but how Missouri hydrologists are working to mitigate threats of future flood events. With the changing climate, it is likely Missouri will witness more frequent flooding and other extreme weather events. This issue will address mitigation steps that The Nature Conservancy and federal agencies have taken in response to the 2019 Missouri River flood event, also a devastating event, as well as the history of how Missouri's agencies adapted to significant flooding. Unlike other Natural Areas Newsletters, this one takes a broad view of our state's situation in the middle of the country, and how we can contribute to conservation and mitigation efforts for wildlife. Perhaps it will offer insight into how we will move forward as a state regarding these large river systems.

— Allison J. Vaughn, editor

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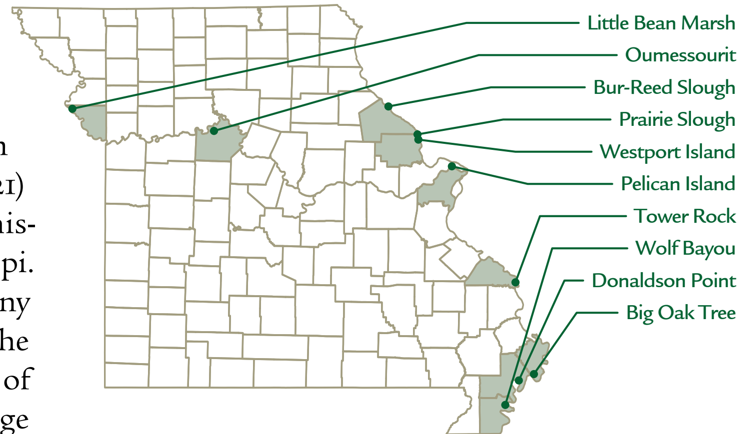
NATURAL AREAS FEATURED IN THIS ISSUE



CONTENTS

NATURAL AREA NEWS

The *Missouri Natural Areas Newsletter* is an annual journal published by the Missouri Natural Areas Committee, whose mission is identifying, designating, managing and restoring the best remaining examples of natural communities and geological sites encompassing the full spectrum of Missouri's natural heritage. The Missouri Natural Areas Committee consists of the Missouri Department of Natural Resources, the Missouri Department of Conservation, the U.S. Forest Service, the U.S. Fish and Wildlife Service, the National Park Service and the Nature Conservancy.

Photo by Quinn Kellner, Missouri Department of Natural Resources

A restored shallow wetland mimics presettlement conditions.

The History of Edward "Ted" and Pat Jones-Confluence Point State Park

by Quinn Kellner and Ronald Colatskie

A narrow strip of land that spans the distance between the two mightiest rivers in North America continues to be shaped and redrawn by the power of the Missouri and Mississippi Rivers as they converge north of St. Louis. Historically, the area harbored wet prairie with borders of pin and swamp white oaks, interspersed with marshes, seasonally inundated pools and narrow hardwood forests fringing the river edges. Hill and swale topography dominated the terrain.

Zebulon Pike boated past the confluence in 1805 and from his riverside view wrote that the west shore of the Mississippi was "a rich prairie, with small skirts of woods." Amos Stoddard described the prairie in 1812, stretching from the mouth of the Missouri along the west bank of the Mississippi "about sixty five miles the width of it is from four to six miles, and in some places it exceeds ten miles. The soil is of luxuriant nature, and yields in abundance; but the want of wood and spring water, of which this prairie is destitute, obliges settlers to plant themselves on the margin of the high grounds." Another traveler noted the "pretty little prairie forming the triangle between the rivers with the trees dropped amongst the prairie resembling distant ships at sea when observed through the haze or at twilight."

As European settlement increased in the 1800's, the occurrence of fire declined and diminished the prairie components so much that the ground converted to forest. Extensive agriculture did not take hold significantly in the confluence until the 1950's when land clearing took place. During that same decade, the construction of numerous petroleum pipelines occurred as they crossed the area to reach Hartford, Illinois. By the end of the 1950's, the confluence was completely open and farmed. An agricultural levee was constructed in the late 1960's.

Today, the confluence is undergoing an ecological restoration transformation. Elevations in the park range from 408 feet to 421 feet at the highest point. Park hydrology is not only impacted by flood events, but also by groundwater connectivity between the park and rivers. Flood events are frequent at the park, with the lower elevations inundated more than 25% of the growing season. All but a few internal high spots experience some inundation every few years.

The 1,118 acres that constitute the park is a good example of what can be accomplished with cooperative partnerships. The initial acquisition of 253 acres was made possible by the Danforth Foundation of St. Louis. Assistance in making the purchase was provided by River Network of Portland, Oregon, which transferred the land to the Department of Natural Resources. A North American Wetland Conservation Act grant allowed the acquisition of an additional 350 acres, which is the focus of wetland restoration. Finally, the United States Army Corps of Engineers owns 515 acres, which is managed as part of the state park. The Danforth Foundation wished to recognize the many contributions of Edward "Ted" and Pat Jones toward the preservation of public lands and the state park was named in their honor. In 2004, the park opened in conjunction with the 200th anniversary of the Lewis & Clark Expedition.

Shortly after the park opened, St. Louis area fourth-grade students planted hundreds of pin and swamp white oaks, pecan, persimmon and Kentucky coffee trees. During subsequent years, students have planted hardwood species covering 40 acres at the park to re-establish wet-mesic forest.

The Missouri River Recovery Program administered by the Corps provided design and construction assistance for restoration of wetland communities and funds for the planting of trees, forbs and grasses since 2008. Ephemeral pools of varying sizes were constructed and attract large numbers of amphibians, reptiles and wading birds. The largest pool is 35 acres and fringed with buttonbush and indigo bush shrubs.

As a stopover on the Mississippi Flyway for migrating birds, the park offers a distinct variety of plant communities to appeal to many species of birds seeking grassland, forest and wetland habitats. Short-eared owls, bay-breasted warblers and American avocets have been observed at the park.

Interpretive features are designed to withstand the park's periodic flood events.

Photo by Scot McNealy Missouri Department of Natural Resources

A federally listed threatened species of false aster, *Boltonia decurrens*, is restricted to moist, sandy floodplains along or near the mouth of the Illinois River. A small population was discovered just outside the park, and seed was collected and broadcast on disturbed ground in the park. *B. decurrens* now thrives with periodic flooding and scouring events that maintain the exposed sandy swales and mudflats that it prefers.

The planting of grasses and forbs commenced in 2007 with work on the wet prairie comprising some 600 acres of the park. Indian and big bluestem grasses were seeded in initially. Forbs including swamp milkweed, white beardtongue, prairie blazing star, rattlesnake master and sawtooth sunflower have been distributed by elevation.

Prescribed fire was introduced in 2013 to encourage the prairie species and reduce competition from cottonwood and willow stands that proliferate in the mudflat communities. Annual or semi-annual burns have been beneficial to the establishment of the prairie species.

Over 17,000 prairie cordgrass *(Spartina pectinata)* plugs have been planted by staff and volunteers at Confluence across 15 years. The cordgrass has been remarkably resilient in its ability to cope with flooding and drought conditions when they occur. Cool season grasses such as Virginia wild rye, orchard grass and fowl manna grass have also been reintroduced in the park. Sedges including Short's, Fox and Yellow-fruited are present. Green bulrush has regenerated and large, circular colonies are common.

Today, the area of the state park is unrecognizable from its conception just over 20 years ago. Much of the transformation has been a natural progression, with natives just needing the opportunity to establish themselves. Others have needed assistance to get a foothold and then proliferated. Whatever the future holds, the confluence remains dynamic and responsive to the power of the rivers. We welcome you to visit and see the process unfold.

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Prescribed fire is often used to restore the prairie natural communities at the park.

Photo by Quinn Kellner, Missouri Department of Natural Resources

Photo by Tyler Goble, U.S. Army Corps of Engineers

A freshly hatched Least Tern next to an egg in a depression on the sandbar.

The Recovery of the Interior Least Tern in Missouri

by Jeff Meshach

As with most human adventures, mine started with a question. In December 2016, I received a call from a U.S. Army Corps of Engineers (USACE) employee working at the Riverlands Audubon Bird Sanctuary, West Alton, Missouri. "Can you band our terns?" Further explanation revealed the organization that previously banded Interior Least Tern *(Sterna antillarum)* chicks from nests on the Riverlands property could no longer conduct banding. My USACE contact heard that World Bird Sanctuary (WBS) possessed a bird banding permit, which was correct, but to band Least Tern chicks requires a recovery permit from the U.S. Fish and Wildlife Service (USFWS). This type of permit allows one to handle federally endangered species, such as the Interior Least Tern. Completing the application was challenging for someone who had not completed such a process, but gathering information to complete the application was enlightening. It was the first time WBS was allowed to work with a non-raptor endangered species.

With a fresh recovery permit in hand, a team of WBS naturalists and volunteers pulled into the Teal Pond Parking lot at 7:30 a.m. Teal Pond is an approximately 10-acre pond near the Rivers Project Office. The USACE employees were already there, placing a boat in the water. We eagerly loaded our equipment in the boat, donned our life jackets and started across the pond to two lashed together barges the terns called their summer home. Traditionally, Interior Least Terns nest on sandbars within the Mississippi and Missouri Rivers, but due to the channelization to allow movement of barges on the big rivers in Missouri, many sandbars have disappeared through time, which naturally reduced the tern breeding habitat and subsequently their popula-

tions in Missouri. Through population research conducted by USFWS and other biologists, terns were listed as endangered species in 1985. The adult terns, coming from Gulf of Mexico wintering waters, migrate to the Riverlands property in mid-May to breed. The barges on Teal Pond are filled with several tons of sand, driftwood and wooden boxes for the tern chicks to hide in. The adult terns have readily accepted USACE's artificial sandbar.

As we approached the barges, the adults took to the skies, rising from their small nest depressions in the sand in a cacophony of shrill screeches. Nest-defending adult terns will sometimes form a feathery squadron, fly at potential nest predators and all defecate in unison as they fly. On this first banding day, we did not experience this behavior. Our pilot deftly parked the boat alongside the barges and the surface of the sand was alive with Least Tern chicks. Tern chicks are unable to fly until approximately 24 days old, and visibly illustrated that the banders were naturally perceived as predators. We counted approximately 35 nests, many of which harbored eggs or chicks too small to run from predators. Treading gently, we caught the larger chicks and placed them in a box for banding. At the banding table was a scribe, two bird banders and one biologist who weighed and sexed the birds. After weighing, one of the banders placed a U.S. Geological Service aluminum band on one leg, reading off the numbers for the recorder, then handed the chick to another bander who placed a plastic, colored band on the other leg. The colored band will allow observers to more easily witness if chicks banded in previous years return to the same barge to breed and rear another clutch.

Meanwhile, the adults, some with small fish in their beaks to feed their chicks, continued to circle the barges waiting for the banding intruders to leave. On this, my maiden banding trip, we placed the banded chicks in a release box. As we placed the last chick in the release box, the recorder yelled out, "Forty-one chicks banded!" Lastly, we gently tipped the release box to allow the chicks to return to their driftwood hiding spots on the barges. Interior Least Terns rear precocial chicks, meaning they are capable of

Game camera capture showing multiple terns landing and hovering over the nesting barge at the Riverlands Migratory Bird Sanctuary in West Alton, Missouri.

Photo by Tyler Goble, U.S. Army Corps of Engineers

Photo by Tyler Goble, U.S. Army Corps of Engineers

Freshly banded Least Tern chick at the Riverlands Migratory Bird Sanctuary.

leaving the nest depression roughly two days after hatching. Leaving their exposed nests to hide among the driftwood and low-growing vegetation on a sand bar makes them less easily seen by predators, such as hawks and herons.

As of 2021, the Riverlands team has banded 191 chicks. The barge was removed in 2022 before the breeding season due to water intake, but will be replaced before breeding season in 2023. Just as importantly, game cameras placed on the barges have captured several adults with colored bands on, telling us that at least some of our banded chicks survived the several thousand-mile journey to wintering waters in the gulf and to return to the Mississippi to continue the cycle. As with any endangered species recovery work, it is encouraging to know that in 2021 the Interior Least Tern was delisted from the endangered list due to the successful recovery of the species. In 2023, the USACE will add a new, artificial nesting island on Teal Pond that will allow even more adults to hatch and rear their young. We all look forward to many tern banding seasons to come.

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From mid-May through August, the least tern makes its home on sandbars and islands in the Missouri and Mississippi River. The least tern is a bird that has adapted to raising its young on desert-like habitats. It lays a nest of one to five eggs in sand or gravel and faces many hazards. In the best of times, the least tern must battle the extremes of the environment. Sand temperatures can range from 55 degrees at night to 125 degrees during the day, so the birds must keep the eggs warm at night and cool during the day for them to survive. They normally have 2–3 eggs in a nest. By staying in a group or colony, least terns can protect themselves from predators. The tiny chicks can run just as soon as they hatch, and they are well camouflaged in the sand. Several breeding pairs will cohabit the same space.

The Mississippi River once provided abundant seasonal sandbar habitat for sustaining populations of interior least terns (Sterna antillarum). Through altered hydrology and changes to the river on the Upper Mississippi River System the natural dynamic that created these successional sandbar islands has been all but lost. The least tern was put on the endangered species list in 1985 and the primary reason that caused the populations to decline has to do with habitat loss and displacement. Since the birds nest right on the shoreline, they are subject to a lot of disruptions. A number of predators are a big threat to nesting least terns along with the effects of water development and water recreation activities destroying tern habitats.

The U.S. Army Corps of Engineers began conducting surveys on the Arkansas, Missouri, Mississippi, Ohio, Red and Rio Grande river systems to document trends and determine the numbers of nesting least terns. From those surveys, the U.S. Army Corps of Engineers began building habitat and islands more suitable for nesting tern habitat through many partnerships with local, State and Federal partners.

The survey information is used to provide important information to our water managers during the least tern nesting season which resulted in water releases from multipurpose reservoirs being modified to support nesting habitat while still supporting authorized purposes.

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A Terrestrial Natural Community on the Move

Big River Sandbars and Mudflats

by Paul Nelson

Nearly 30 years ago, I watched from my Jefferson City office window on the 9th floor as the Missouri River crested to an all-time high. The Great Flood of 1993 transformed the floodplain forever, washing out Highway 54 before me, destroying Great Central Lumber, burying cornfields under several feet of sand, and scouring deep "blue holes." Conservation opportunities followed with the creation of the Big Muddy National Wildlife Refuge.

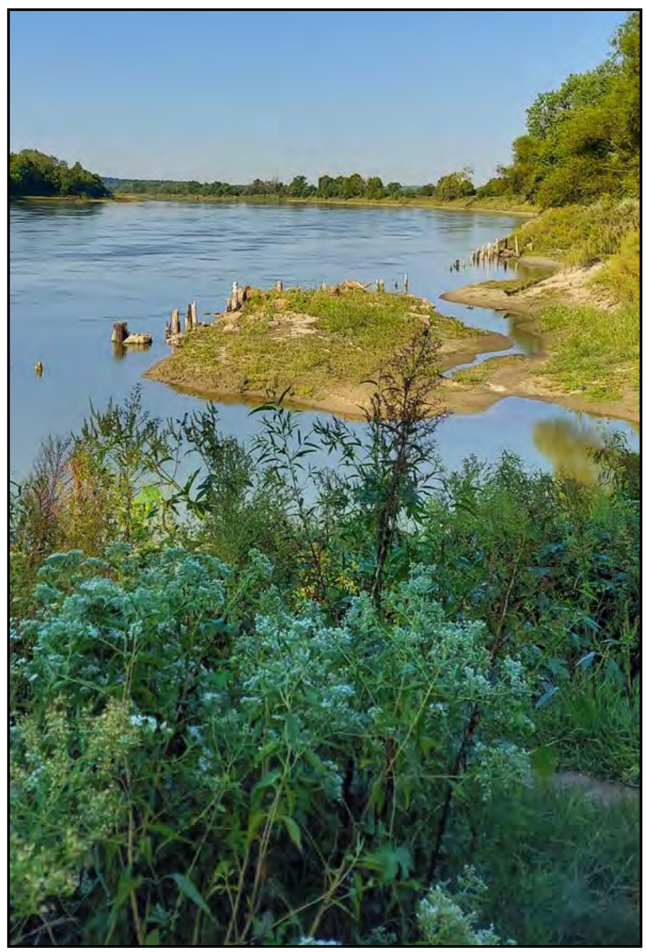
The following summer, I visited some of the large areas of deposited sand and new riverbanks to discover plants whose seeds were deposited by upstream floodwaters. Among the plants I discovered included the rare oriental tick-seed *(Corispermum villosum)* and round-headed prairie clover *(Dalea multiflora)*.

Hydrochory is the transport of seeds by water, an important mechanism for dispersal of riparian plant species (Nilsson and Jansson 2010). Imagine the possible (and probable) delivery of seeds on the conveyor of flowing waters coursing the vast thousands of square miles in the Missouri River watershed, as far upstream as Bozeman, Montana. Nearly 30 years later, no Missouri River flood event has matched the power of 1993, as it left acres upon acres of barren sand and debris ripe for the germination of plant seeds drifted from afar. No other natural community is subject to this seed dispersal mechanism; seeds transported on the feet of waterfowl pale in comparison.

While the vast and complex braided channels, sloughs, marshes, sandbars, and mudflats of the once-meandering Missouri River have been tamed by channelization, the process of seed transport and opportunistic habitat still exists on the big river systems in the state. After the significant flood of 2019, by summer 2022 the Missouri River witnessed record low water levels that exposed historic steamboats and other artifacts. And so, I traveled to several locations along the river to search for characteristic and unusual flora associated with this hydrochory transport system.

Where the Missouri River makes a bend near Fort Leavenworth, Kansas (Figure 1), I stopped at one of the river accesses to discover such characteristic plants in the sand and mudflat deposits along the riverbank as creeping love grass

Figure 1. Bend in the Missouri River looking upstream across from the Leavenworth Bottoms in Kansas.



All photos by Paul Nelson

Figure 2. Vegetation along the upper shoreline of an oxbow lake after 2019 floodwaters receded.

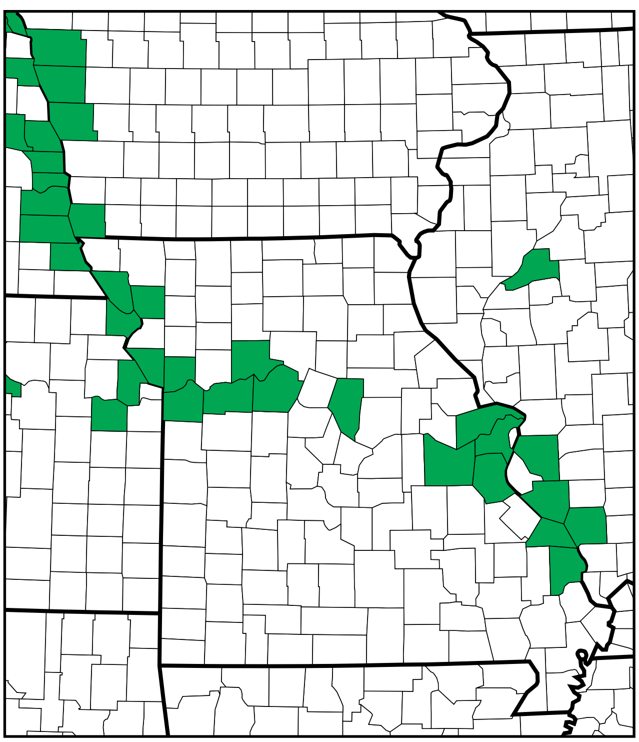


Figure 3. Distribution of bushy cinquefoil *(Potentilla supina* ssp. *paradoxa)*. Note this species is restricted to counties along the Missouri and Mississippi rivers. Source: The Biota of North America Program plant atlas.

(Eragrostis hypnoides), red sprangletop *(Leptochloa panacea* ssp. *mucronata)*, nodding bur marigold *(Bidens cernua)*, ball sedge *(Cyperus echinatus)*, the adventive Russian thistle *(Salsola tragus)*, knee grass *(Panicum dichotomiflorum)*, and the adventive Indian heliotrope *(Heliotropium indicum)*.

Traveling north and stopping at other river access points and wetlands impacted by the 2019 flood, I visited an old Missouri River oxbow lake. Various predictable zones of water-borne plant species germinate as water recedes from drought. Along the upper shoreline of this low water oxbow (Figure 2) are populations of water hemp *(Amaranthus tuberosus)*, pale smartweed *(Persicaria lapathifolia)*, pinkweed *(P. pensylvanica)*, nodding bur marigold *(Bidens cernua)*, pitseed goosefoot *(Chenopodium berlanderi)*, false aster *(Boltonia asteroides)*, and the adventive salt marsh aster *(Symphyotrichum subulatum)*. These shoreline bank species give way to the water-borne seeds deposited as lake waters receded. Here, a 10 ft.-wide zone includes thousands of maturing sedge species in the genus Cyperus including red-rooted sedge *(C. erythrorhizos)*, ball sedge *(C. echinatus)*, and fragrant sedge *(C. odoratus)*. Within this matrix are slender false pimpernel *(Lindernia dubia* var. *anagallidea)*, Yerba De Tajo *(Eclipta prostrata)*, Obe-Wan-Conobea *(Leucospora multifida)*, and marsh yellow cress *(Rorippa palustris* var. *fernaldiana)*. A few scattered bushy cinquefoil *(Potentilla supina* ssp. *paradoxa)* plants (a S2 species of conservation concern) were widely scattered in this matrix (Figure 3).

My final stop in late summer 2022 was at the confluence of the Osage and Missouri rivers, near Bonnot's Mill, Missouri. Here on the upper shoreline were populations of late boneset *(Eupatorium serotinum)*, cocklebur *(Xanthum strumarium)*, water hemp *(Amaranthus tuberosus)*, the blue-flowered

mistflower *(Conoclinium coelestinum)*, bugleweed *(Lycopus virginicus)*, and scattered cottonwood saplings *(Populus deltoides)* line the upper shoreline at normal water level. Note however in Figure 4 the distance at which the river receded perhaps 1,000 feet beyond this shoreline.

Extending beyond this shoreline, transported seeds (mostly annuals) germinated 30 ft. (Figure 5) from the edge of the zone forming a nearly solid cover, eventually thinning out to sparse ribbons of plants at parallel elevations determined by the variable ebb and flow of the fluctuating water levels. Among the many plants found in this zone and extending onto the sandy flats include carpet weed *(Mollugo verticillata)*, toothcup *(Rotala ramosior)*, creeping love grass, cockspur grass *(Echinochloa muricata)*, red sprangletop, ball sedge, and common dwarf bulrush *(Lipocarpha micrantha)* (Figure 6).

I observed and recorded all of these riverbank and mudflat plants at four locations in about 2 hours, yielding two species of conservation concern. Most notable about the process of hydrochory on big rivers like the Missouri is that new discoveries await around every river bend. In most Missouri natural communities, it is the stability of the community that supports rare plants. But in this highly unstable community shaped by hydrochory, it is fascinating to discover rare plants growing in Missouri from seed that originated perhaps 1,000 miles upstream. I, for one, plan on more river visits by kayak when the conditions permit.

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Cited Literature:

Nilsson, C, Brown R.L., Jansson R, Merritt D.M.. 2010. The role of hydrochory in structuring riparian and wetland vegetation. *Biol Rev Camb Philos Soc*. 2010:85 (4): 837–858.

Figure 4. A streambank zone of vegetation along the Osage River in Bonnots Mill.

Figure 5. A riverscape scene during the 2022 drought looking toward the mouth of the Missouri River (in the distant gap) one mile downstream.

Figure 6. Closeup of common dwarf bulrush (Lipocarpha micrantha) on the sandy flats of the Osage River.

Hydrology and Water Quality of Little Bean Marsh Natural Area

A Remnant Riparian Wetland along the Missouri River

by Dale Blevins

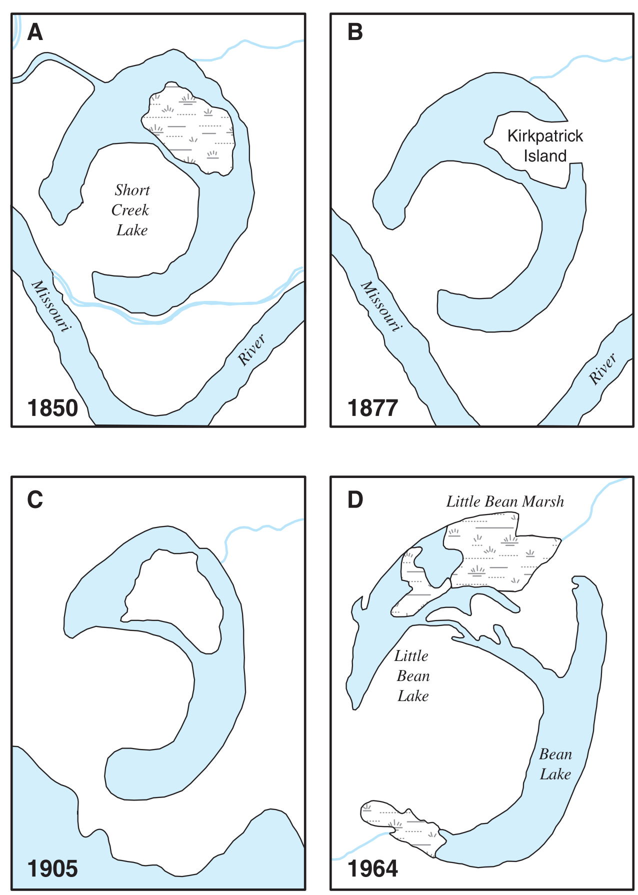
Little Bean Marsh is a Missouri Natural Area and represents a small remnant of a large complex of riverine wetlands that covered much the Missouri River floodplain. Indeed, Little Bean Marsh appears as a small island in a sea of agriculture from above. Somehow Little Bean Marsh was never drained or farmed and still has many natural characteristics typical of once endless wetlands along the Missouri River. Little Bean Marsh was selected for this study because it is one of only a few remaining riparian wetlands along the Missouri River where nutrient-cycling processes were expected to be relatively undisturbed. Therefore, understanding limnological characteristics of a wetland like Little Bean Marsh provides insights into the historical hydrologic and water-quality functions and processes of Missouri River wetlands, the effects and benefits of wetland restorations, and guidance for wetland-management policies.

Little Bean Marsh is a remnant of a much larger oxbow of the Missouri River that once included Bean Lake. Bean Lake and Little Bean Marsh were separated by sediments dropped by Short Creek which drains the highly erosive loess hills to the east. Short Creek now bypasses Little Bean Marsh and drains directly into Bean Lake, decreasing the marsh's connection with surface runoff.

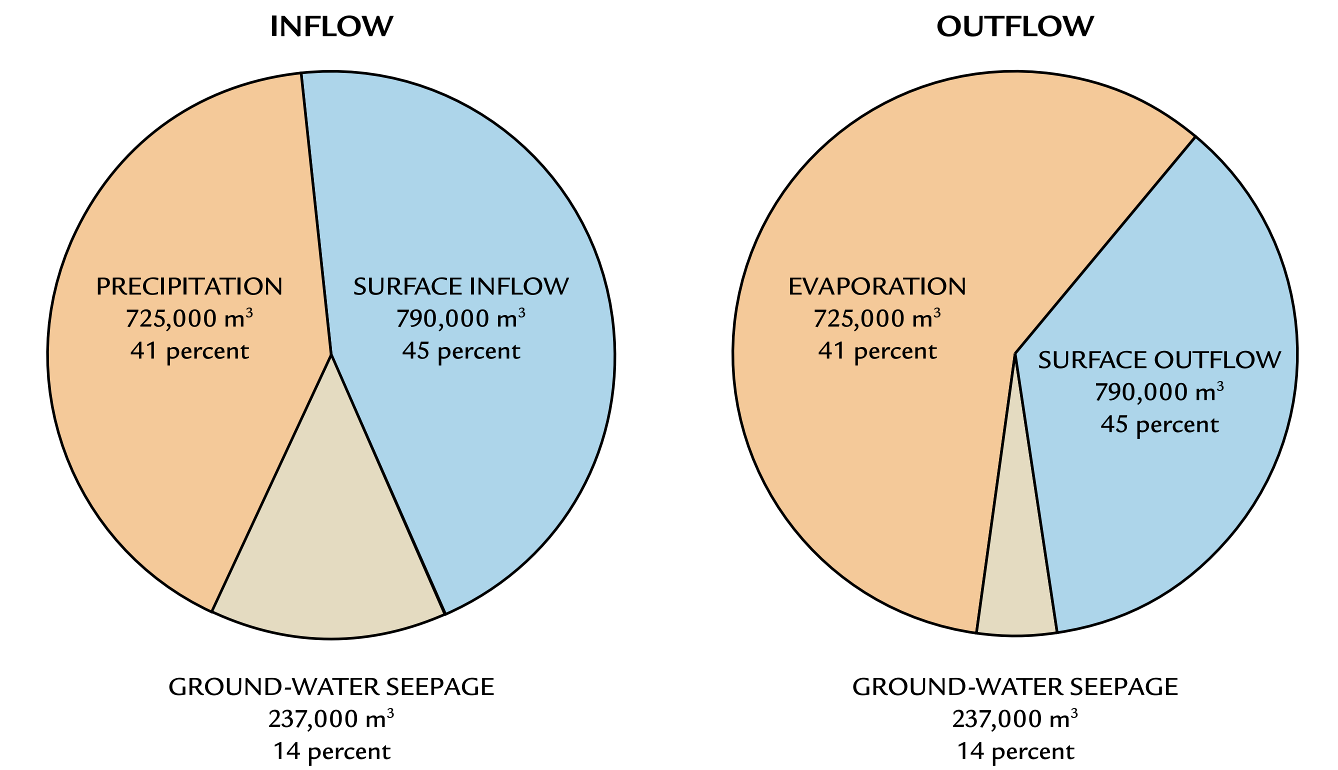
Hydrology

Little Bean Marsh averages about 69 hectares in size, has a maximum depth of about 1 meter, and the majority of the marsh is covered by macrophytes. In 1997, hydrologic measurements of ground-water levels, marsh water levels, surface-water inflows and outflows were made over a 12-month period in 1996 and 1997. 41 percent of the water received by Little Bean Marsh was from direct precipitation, 14 percent from groundwater seepage, 30 percent from watershed runoff, and 15 percent from backflows from Bean Lake. Like many flood plain water bodies, more than 90 percent of the marsh's drainage area is flood plain. The nearly flat slopes, sandy soils, and large shallow depressions keep runoff coefficients in the flood plain low. No runoff was observed from several storms that had more than 4 cm of rain; consequently, surface-water contributions from the watershed were small. River levees and

Historical evolution of Little Bean Marsh
(Castner and LaPlante, 1992)



Maps, graphs and diagrams courtesy of Dale Blevins

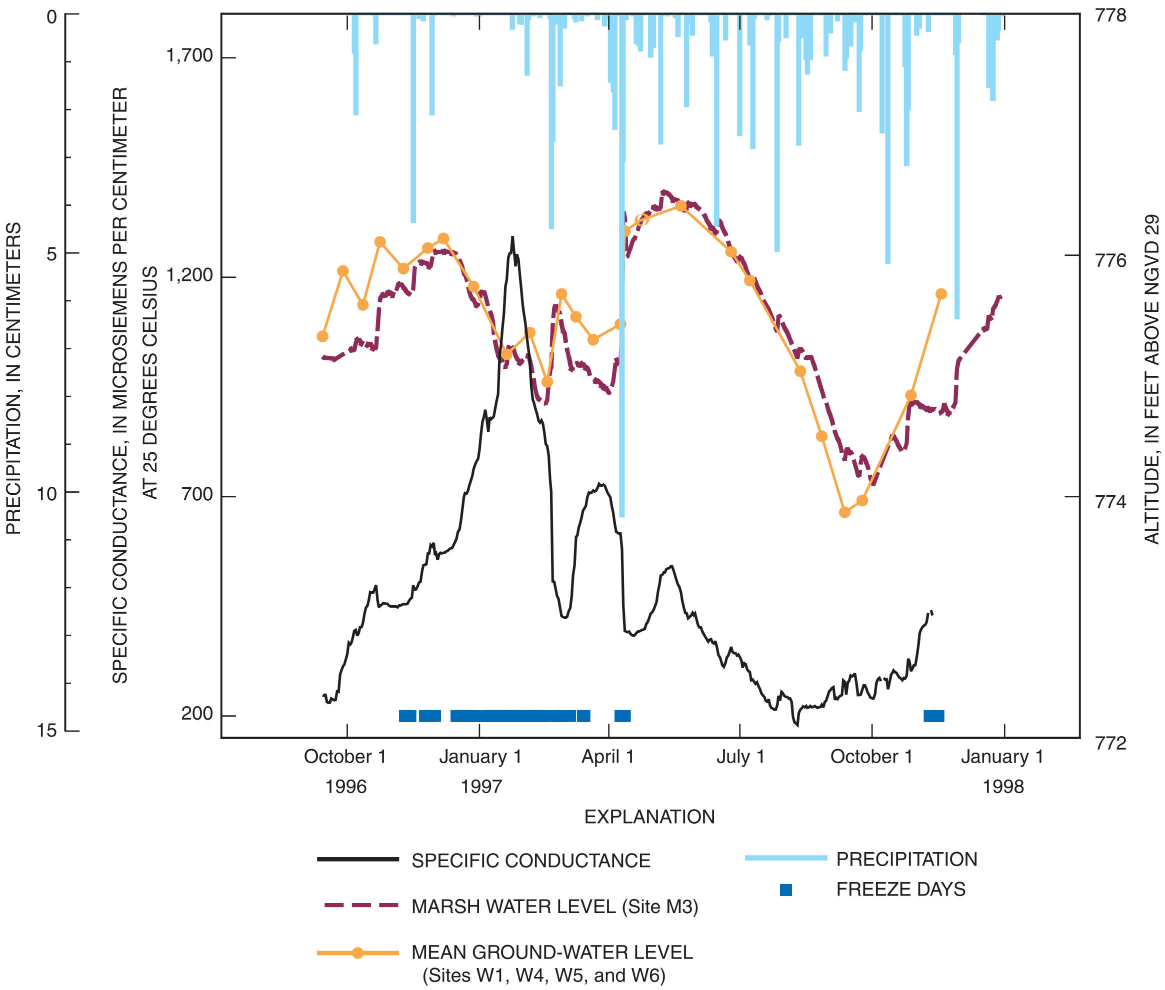


Inflow and outflow water budgets for Little Bean Marsh during 1997

floodplain drainage have converted Little Bean Marsh and many other Missouri River wetlands from open to closed systems. Open wetlands typically are large sinks for alloctanous sediment and nutrients, whereas closed wetlands rely primarily on precipitation for nutrients. Consequently, the hydrology, water quality, and ecological functions of remnant wetlands located along today's Missouri River usually are substantially different from the predevelopment condition.

Groundwater levels near Little Bean Marsh did not closely track Missouri River stages primarily because of the 1.6 km distance separating them. However, groundwater levels closely tracked marsh water levels indicating a substantial hydraulic connection between groundwater and the marsh. Although Little Bean Marsh was both a recharge and discharge area, ground water entering the marsh was three times the recharge to groundwater. Groundwater typically recharged the marsh on the north side, and marsh water seeped down through the marsh bottom on the south side. The close interaction with shallow ground water indicates lowering of the water table by as little as 1 m by pumping would likely make Little Bean Marsh much drier, and could substantially affect the marsh ecosystem. Reduced surface runoff and ground-water availability is a stabilizing influence on marsh hydrology, and probably leads to the persistence of emergent vegetation. The groundwater connection of Little Bean Marsh indicates that the hydrologic regime of most wetlands along the lower Missouri River is largely a function of marsh depth relative to the water table.

More water was lost from the marsh through evapotranspiration (59 percent) than all other pathways combined. This characteristic partially is because of abundant macrophytes that can increase evapotranspiration above that lost from open-water surfaces. Surface outflow accounted for 36 percent and groundwater seepage accounted for only 5 percent of the losses. Long residence times and large evaporative losses allow Little Bean Marsh to perform the hydrologic functions of peak-flow attenuation and



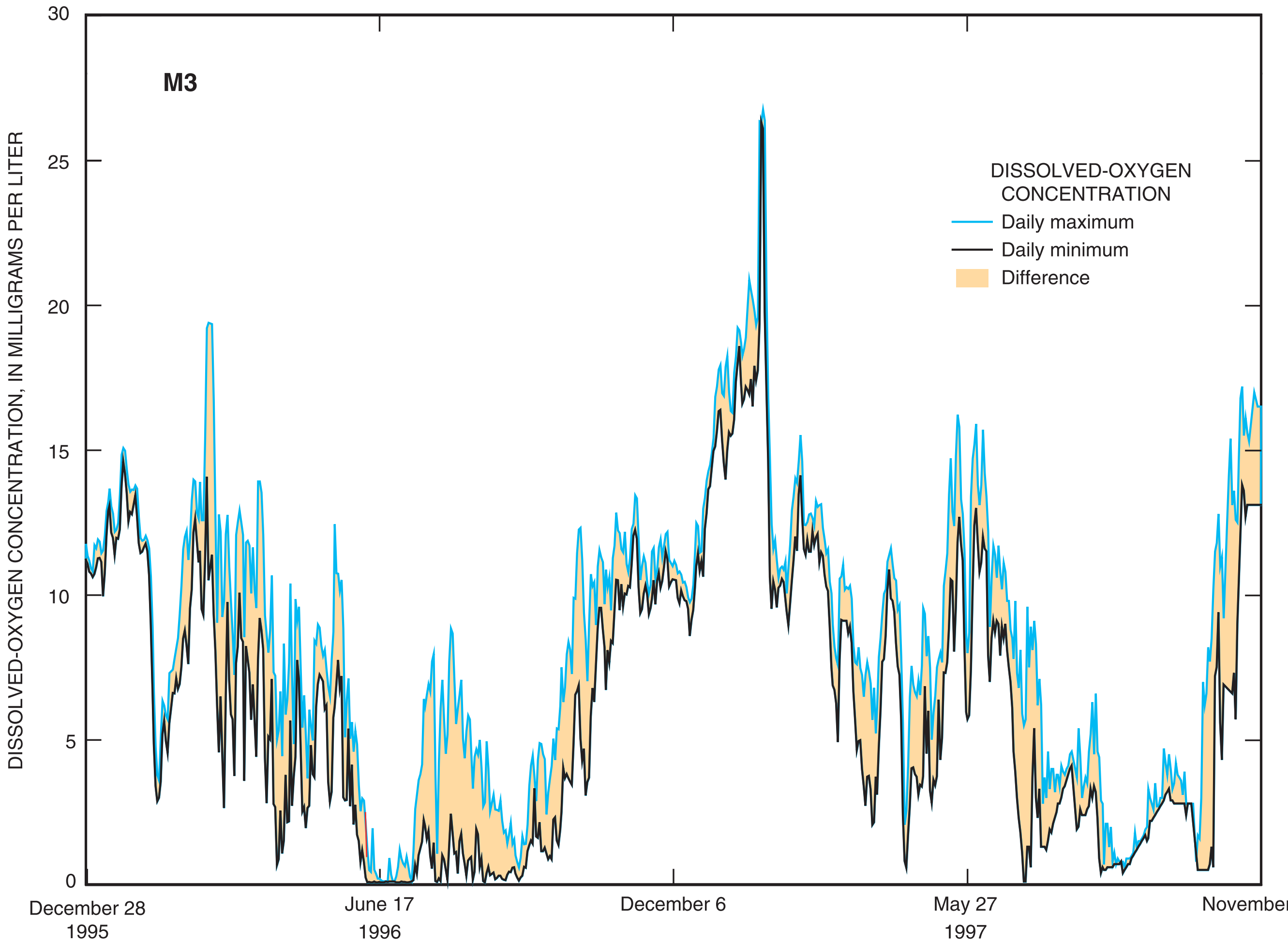
Specific conductance, marsh water level, mean ground-water level, precipitation, and days with mean air temperatures below 0 degrees Celsius at Little Bean Marsh

surface runoff reduction. Routing of streams, like Short Creek, around marshes obviously precludes these benefits. Large residence times also allow the marsh to greatly affect water quality before water escapes as groundwater recharge or surface outflow.

Water Quality

The greater percentage of precipitation as an inflow source has diluting effects on all water quality constituents, and the substantial difference between specific conductance of groundwater and precipitation/surface runoff make specific conductance a useful indicator of the primary source of water in the marsh at a given time. However, because of the shallowness of the marsh, ion exclusion during ice formation in the winter caused the greatest specific conductances during the entire monitoring period. This substantial increase in the concentration of all dissolved solutes could make wetlands more vulnerable to toxic contaminants in the winter than other surface water bodies.

Dissolved oxygen concentrations were less than 5 mg/L for 3 to 4 months in 1996 and 1997, and were near zero for about 1 month during the summers of both years. These periods of anoxia produce widespread reducing conditions that inhibit nitrification, enhance denitrification, and cause iron reduction and phosphorus (P) release. The largest diel changes were about 5 mg/L that often occurred during periods of low dissolved



Daily maximum and minimum dissolved oxygen concentrations at site M3 in Little Bean Marsh.

oxygen concentrations. Dissolved oxygen concentrations were significantly greater at open water sites than at sites with emergent vegetation because of shading and decomposition of a large amount of detritus. These extended periods of anoxia during the summer undoubtedly limit the habitat for certain fish and other fauna that have not adapted to low oxygen conditions and have no refuge in a shallow marsh.

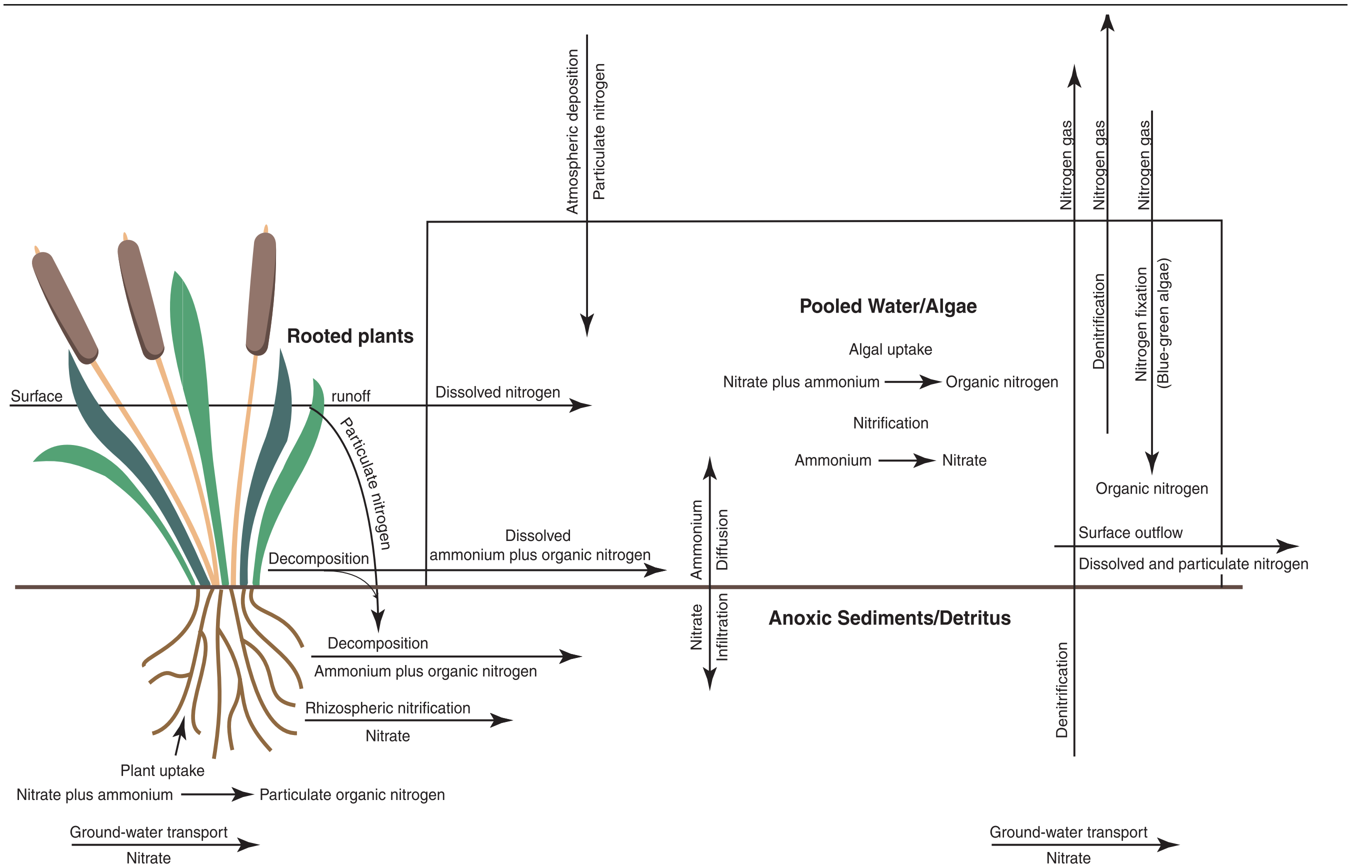
Water temperatures peaked between 25 and 30 °C for almost 2 months each year. Despite depths of less than 1 m, vertical temperature differences of 3 to 9 °C persisted for more than 3 months during the summers of 1996 and 1997. The period of least dissolved-oxygen concentration corresponded with the period of maximum stratification. The ability of open water marshes to stratify increases the area and periods of time with reducing conditions that inhibit nitrification and potentially cause denitrification and P release from iron reduction. Chlorophyll data indicate that much of Little Bean Marsh underwent a major algal bloom in September 1997, shortly after summer stratification abruptly ended. The bloom may have been triggered by mixing of the water column that made ammonia nitrogen (N) from the hypolimnion available to a N-limited population of algae. Shallow depths and extended periods of anoxia in the marsh would limit the ability of some organisms to escape high temperature stress.

Denitrification and biotic uptake kept concentrations of inorganic N extremely small. This situation contrasts with N in the Missouri River and many of its tributaries, where nitrate (NO_3) is the dominant species of N. Consequently, artificial floodplain drainage that bypasses wetlands can deliver substantially more biotically available inorganic N to receiving streams than surface water that has been routed through a remnant wetland.

Water clarity in Little Bean Marsh was usually high for several reasons. Sediment loadings from the largely floodplain drainage were low, emergent vegetation shade out algae and shield the water from wind, and high concentrations of bivalent cations increase flocculation rates of inorganic suspended material. The high divalent cation concentration in the marsh probably was a result of groundwater received by the marsh. Open water sites had significantly greater turbidities and suspended sediment concentrations than sites covered with emergent vegetation. This difference was likely caused by shading that limited algal growth in vegetated sites. Consequently, marshes along the lower Missouri River are likely to have better water clarity if they are incised deep enough to receive substantial amounts of ground water and grow abundant emergent macrophytes.

Little Bean Marsh usually was either eutrophic or hypereutrophic. Vegetated sites had less persistent periods of eutrophy. The most intense period of hypereutrophy occurred in September, and coincided with both an algal bloom and senescence of river bulrush *(Bolboschoenus fluviatilis)* and cattails *(Typha latifolia)*. The rapid leaching of N that occurs soon after macrophyte senescence, combined with a recent destratification of the marsh, probably provided N to the N-limited open-water areas and triggered a phytoplankton bloom. This type of bloom could be a common phenomenon in Missouri River wetlands with thick stands of macrophytes.

Conceptual compartments and dominant processes involving nitrogen in Little Bean Marsh.



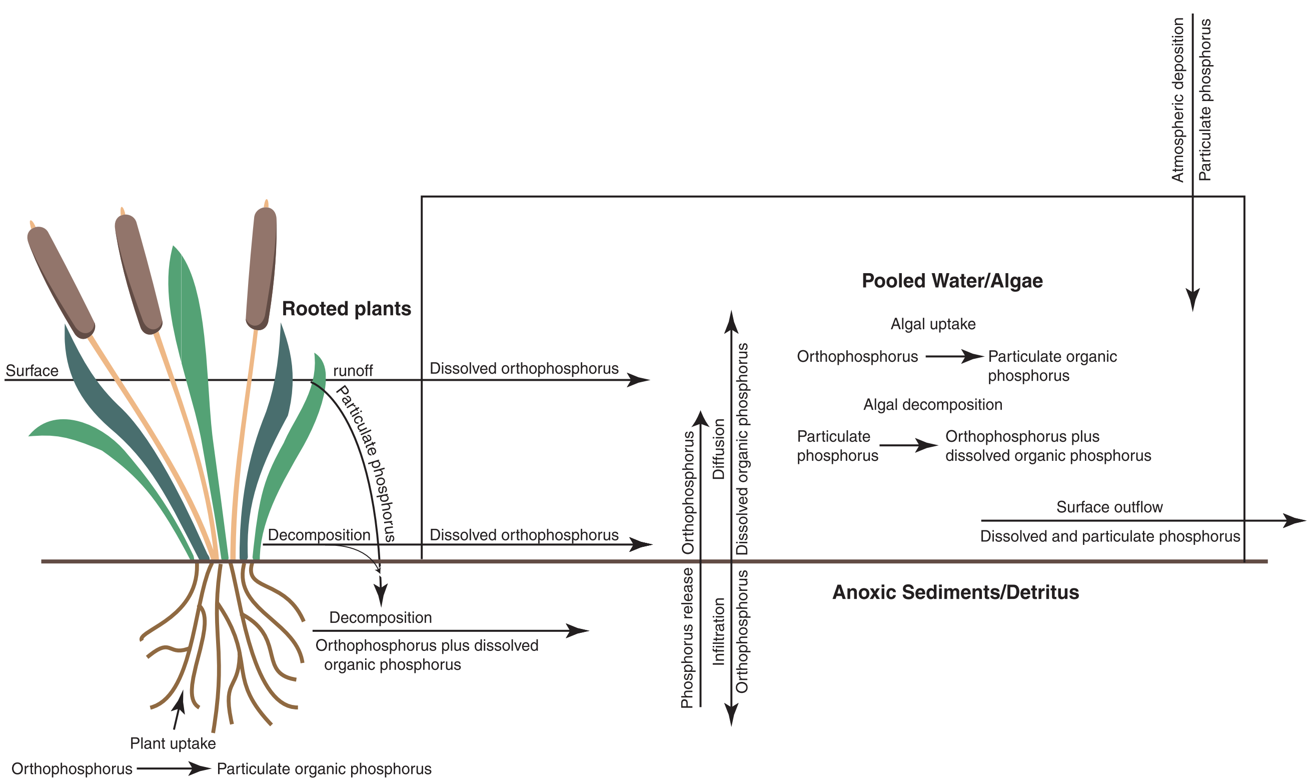
N was better correlated with chlorophyll than was P at open-water sites, indicating N is more limiting than P on phytoplankton growth. The lack of any correlation of chlorophyll with N or P at some vegetated sites is consistent with light limitation.

Despite the rarity of runoff events, surface runoff, combined with atmospheric deposition, contributed more than seven times the 530 kg (kilograms) of N that escaped Little Bean Marsh in surface outflow in 1997. Atmospheric deposition alone was more than the 530 kg. Ground water contributed less than 1.5 percent of the N leaving the marsh in surface outflow. Undoubtedly, much more N is internally recycled through plants in Little Bean Marsh than is externally gained or lost annually. The slow decay rate of river bulrush and reducing conditions in bottom sediments potentially make burial of organic N a substantial sink of N. Annual peak concentrations of nearly all N and P species occurred during the fall period of senescence.

Results of denitrification experiments indicate that denitrification rates were limited by NO_3 in the water column. Consequently, decomposition and nitrification of ammonium (NH_4) and organic N are the rate-limiting steps of N removal in Little Bean Marsh. Conditions for high rates of denitrification were almost ideal in the bottom sediments of the marsh. The dominant macrophytes in the marsh were river bulrush and cattails; both have oxidizing rhizospheres around their roots. These rhizospheres greatly increase rates of the rate-limiting decomposition and nitrification processes over rates occurring in open-water areas where all NO_3 must diffuse from the water column through the sediment/water interface, as opposed to being created in the sediments. The NO_3 limitation on rates of denitrification also indicate that Little Bean Marsh has a large unused capacity for N removal.

Only the largest storm had a measurable effect on P concentrations in Little Bean Marsh. Most

Conceptual compartments and dominant processes involving phosphorus in Little Bean Marsh.



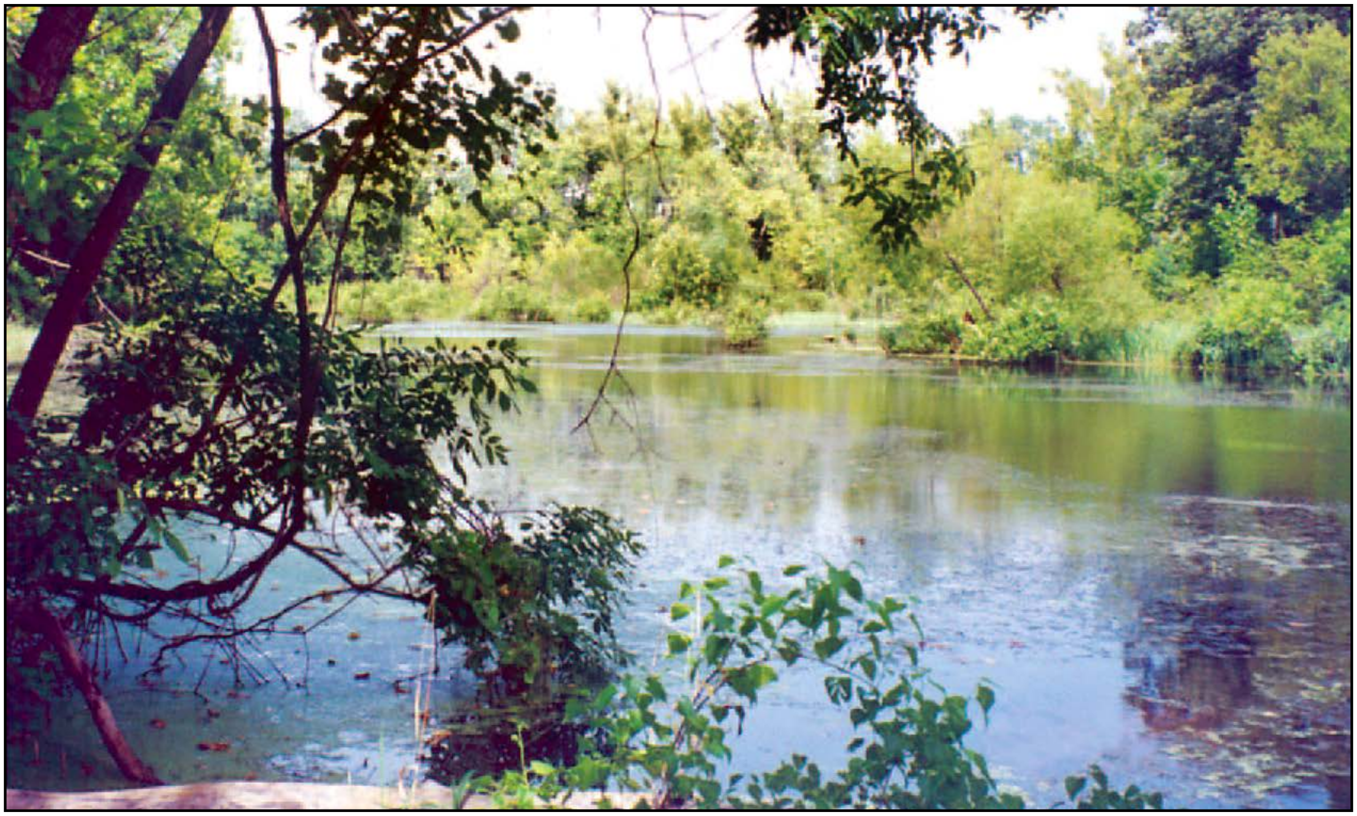


Photo courtesy of U.S. Geological Survey

Little Bean Marsh Natural Area is a remnant wetland along the Missouri River

dissolved P usually was in the orthophosphate (PO_4) form, but most total P was on particulates. Correlations of wind speed, pH, turbidity, and dissolved oxygen with concentrations of total P indicate that periods of anoxia have much larger effects on P release than the other variables. Periods of most extreme anoxia occurred in late summer and corresponded with high rates of decomposition and senescing macrophytes to produce the highest concentrations of both N and P and a large algal bloom in Little Bean Marsh. Low water levels prevented the escape of P in surface outflow during the periods of highest P concentrations. Annual climatic patterns in the Midwestern United States probably make the correspondence of these conditions common in marshes along the Missouri River.

Little Bean Marsh removed the majority of the P it received. The amount of P in surface inflows to the marsh were more than one order of magnitude greater than that escaping in surface outflows. P contributions from atmospheric deposition to the marsh are small compared to the 53 kg of P in surface outflows in 1997. Low concentrations of P in ground water caused ground water to be a small source of P to Little Bean Marsh as well. The long hydraulic residence time of the marsh and large contributions of iron from ground water (that provide many sorption sites for P) make the marsh an effective sediment and P trap. These characteristics, plus the large long-term retention of P by the macrophytes after senescence, make burial of P a substantial sink of P in Little Bean Marsh.

Concentrations of NO_3 in Little Bean Marsh usually were less than 0.005 mg/L and were significantly less than concentrations in the Missouri River ($p<0.0001$), which averaged 1.1 mg/ L. Large rivers, such as the Missouri, typically have low amounts of primary production because of turbidity, large depths, and constant mixing. Consequently, inorganic nitrogen is not rapidly

removed and can build up to substantial concentrations in large rivers, such as the Missouri and the Mississippi, and can cause large zones of oceanic hypoxia, such as in the Gulf of Mexico, which typically are N limited.

Dissolved organic N was the dominant N species in Little Bean Marsh and other Missouri River wetlands. Consequently, concentrations of organic N in Little Bean Marsh and the Missouri River were not significantly different. Wetlands such as Little Bean may not reduce the amount of organic nitrogen in receiving rivers. Suspended organic material in rivers is often refractory, however, and not readily available to biota. Nevertheless, the vast historical extent of riparian marshes along the Missouri and Mississippi Rivers may have had a substantial role in limiting NO_3 loads to the Gulf of Mexico before agricultural development of floodplains. Drainage and removal of riparian marshes may be a primary cause of the increased NO_3 loads to the Gulf of Mexico today.

Annual mean concentrations of total and soluble reactive P were both less in Little Bean Marsh than the Missouri River; therefore, the water contributed from Little Bean Marsh and marshes like it would likely decrease the concentration of P in the Missouri River, despite the potential for occasional P release during periods of wetland anoxia.

Whereas the data indicate that Little Bean Marsh has the capacity to remove much more N and P than is presently removed, large quantities of additional sediment and nutrients could alter species composition of wetland vegetation and cause other hydrochemical changes. For example, rerouting of Short Creek through Little Bean Marsh might allow the removal of additional N from runoff through denitrification, but also might cause the marsh to fill with sediment. Because remnant riparian wetlands along the lower Missouri River are so rare, preservation of these wetlands may be more important than using them to improve the quality of downstream and downgradient waters such as the Missouri River.

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https://pubs.usgs.gov/sir/2004/5171/pdf/complete.pdf

Photo courtesy of U.S. Army Corps of Engineers

Damage on the L536 showing breaches and water flowing through them

Collaboration in Large-scale Levee Setbacks Along the Missouri River

2019 Flood and Beyond

by Dave Crane[1] and Viv Bennett

2019 Flood Background:

During the fall months of 2018, the lower Missouri River Basin experienced a very active weather pattern and above-average rainfall resulting in wet soil conditions heading into the winter season. Extreme winter temperatures, particularly in February and early March 2019, resulted in a deep frost within the nearly saturated soils. An active storm pattern across the plains developed resulting in record snowfall in parts of the lower basin with one to four inches of snow water equivalent (SWE) persisting as late as March 12, 2019. The extreme cold temperatures also resulted in the development of thick ice on streams and rivers within the region.

Temperatures over the lower Missouri River Basin quickly warmed in conjunction with a heavy rain event from March 12 to March 14, 2019. Widespread rainfall totals of one to three inches were observed across the region with pockets receiving up to four inches in eastern Nebraska and southeastern South Dakota. The warmer temperatures resulted in significant snowmelt, generally one to three inches of SWE, which combined with the heavy rainfall on top of frozen saturated soil to produce high runoff. Unregulated streams in eastern Nebraska, southeastern South Dakota and western Iowa experienced extremely high flow rates with many setting new records including tributaries of the Missouri River upstream and downstream of Gavins Point Dam. Several

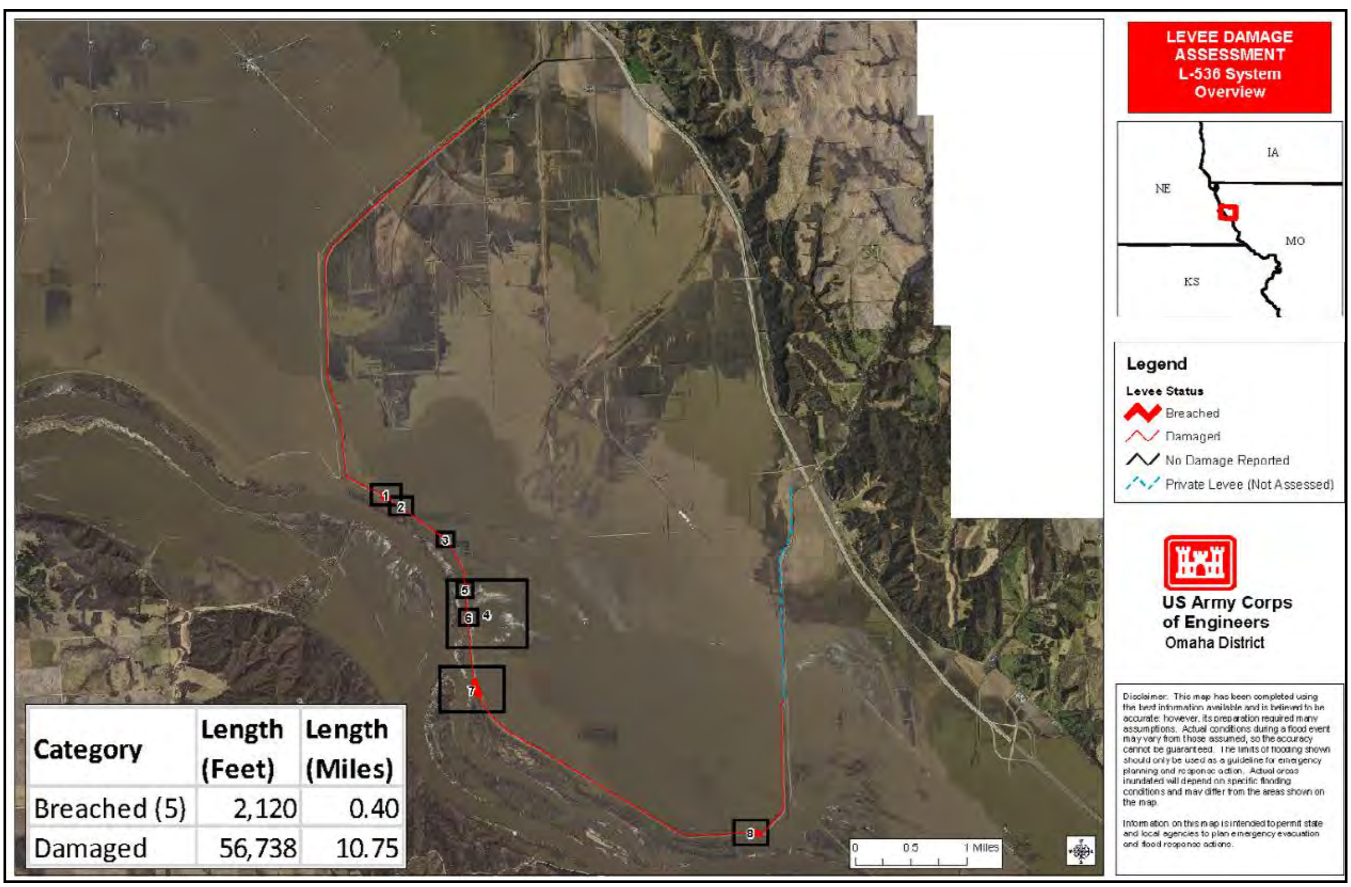
1 The views, opinions and findings contained in this article are those of the authors(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other official documentation.

ice jams were reported during this event and contributed to record stages in some locations. Most of the precipitation that fell upstream of Fort Randall Dam on the mainstem Missouri River fell as snow and did not produce significant short-term runoff. As a result of this event, the mainstem Missouri River experienced high flows, picking up large inflows from unregulated tributaries in southern South Dakota, western Iowa and eastern Nebraska. Record flows and stages were observed on the Missouri River south of Omaha in the proximity of and downstream of the confluence of the Platte River.

The river flows overtopped the L-536 levee, initiating erosion of the levee crest, ramps, landward side slope, and the levee/berm toe. Flood damages caused five breaches (four inlet, one outlet) and additional reaches of critical section loss (i.e., "partial breaches"). The levee sponsor, Atchison County Levee District No. 1 (ACLD) provided a letter to the U.S. Army Corps of Engineers Omaha District (NWO) dated March 28, 2019 requesting rehabilitation assistance on the Missouri River Levee Unit L-536. The NWO completed a Project Information Report (PIR) dated May 28, 2019 requesting funds to conduct detailed engineering and design to prepare for levee repair. Due to the severity of damages and the lack of access, levee damages could not be fully assessed until early 2020.

The Rock Creek tieback levee on the upstream end of the L-536 levee system was minimally damaged compared to the Missouri River reach and downstream Mill Creek tieback. Figure 1 (below) and Figure 2 (following page) present 2019 aerial imagery of the damaged levee with breach locations identified. Through 2019 and periodically in 2020, the system continued to be partially inundated with the majority of inflow through Breach F. The majority of the outflow exited through a breach in the Mill Creek Right Bank levee to the north of the L-536 levee Mill Creek tie-back.

Figure 1. Full L-536 levee system damage map



Category	Length (Feet)	Length (Miles)
Breached (5)	2,120	0.40
Damaged	56,738	10.75

Maps courtesy of U.S. Army Corps of Engineers

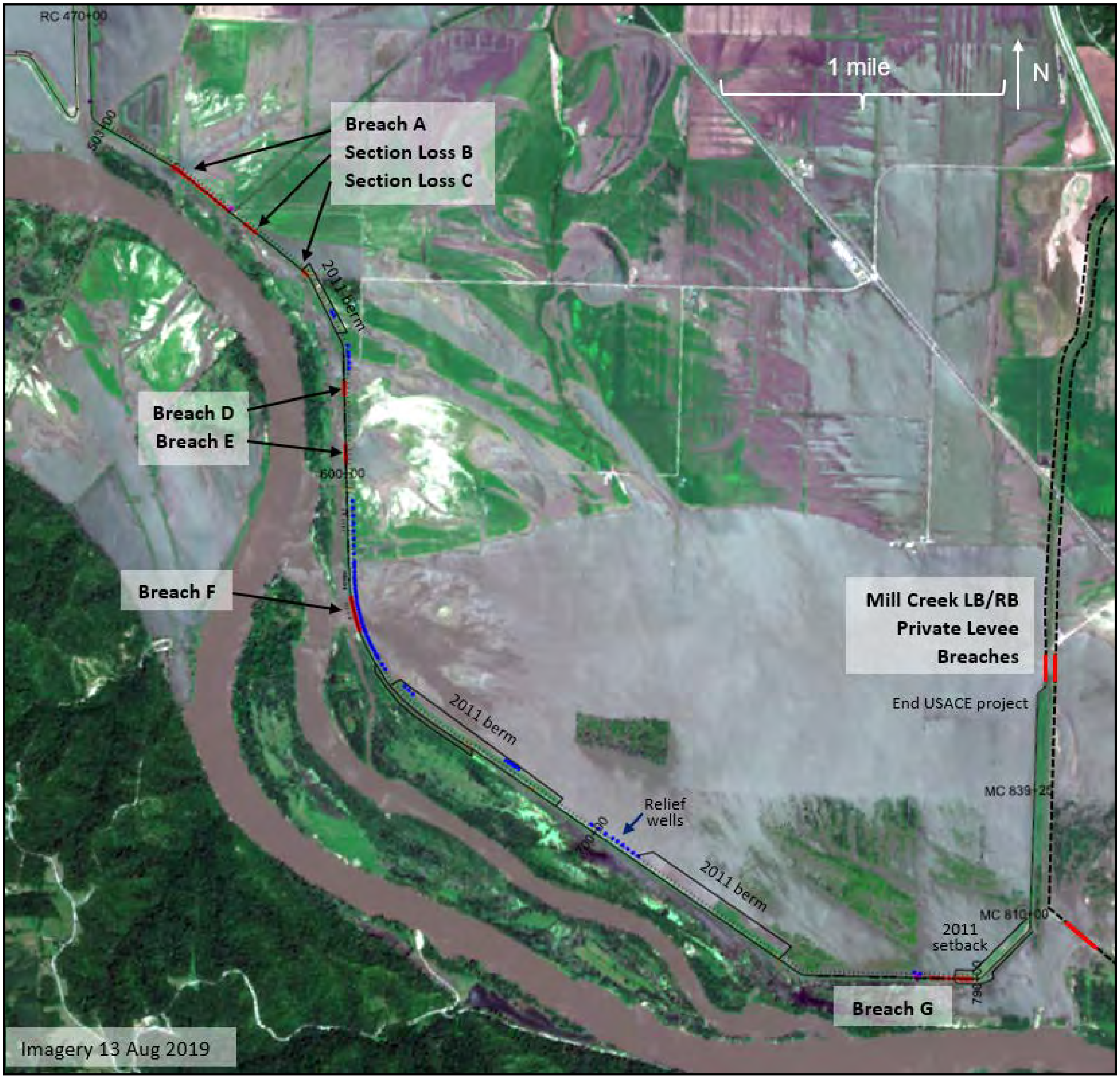


Figure 2. L-536 breach location map

L-536 Levee Rehabilitation Project Authority and PL 84-99 Eligibility

One of the missions of the U.S. Army Corps of Engineers (USACE) is the Emergency Levee Rehabilitation Program and the Advanced Measures Civil Emergency Management Program under the authorities/ guidance of 33 U.S.C. 701n (commonly referred to as Public Law 84-99 or PL 84-99); Army Regulation 500-60, Disaster Relief; and Engineer Regulation 1130-2-530, Flood Control Operations and Maintenance Policies. These statutes and regulations allow the USACE to provide a levee rehabilitation program for repairing levees after flood events and perform advanced measures prior to flooding or flood fighting to protect against loss of life and significant damages to urban and/or public facilities.

To be included in the PL 84-99 program, levees must be routinely inspected and meet construction, operation, and maintenance standards set by the USACE. There are two main categories of levees included in the program;

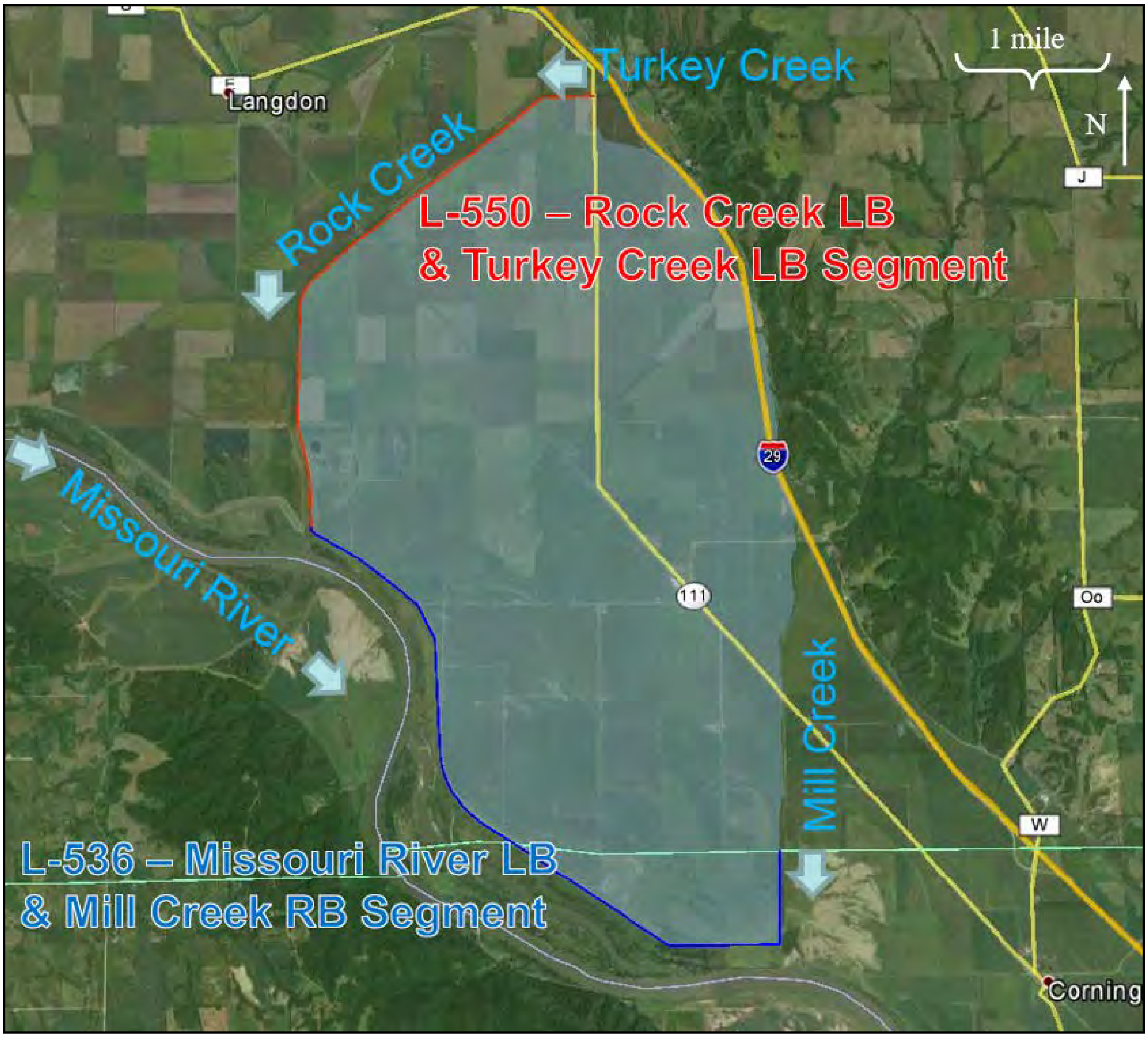
non-federal and federal levees, based on the entity that originally constructed them. Both of these categories of levees can include agricultural and urban levees. Levee rehabilitation under PL 84-99 is generally intended to restore the same level of flood risk protection to a damaged area that existed prior to any flood damage. The Engineer Regulation 500-1-1 (Civil Emergency Management Program) describes the conditions that must be met in order to be eligible for rehabilitation assistance under the PL 84-99 program.

Provided that the least cost, most technically feasible structural repair alternative (the most commonly selected repair option) is selected for rehabilitation of a damaged federal levee, construction is performed at 100% Federal cost.

L-536 Project Location

As depicted in Figure 3, the L-536 levee rehabilitation project is located in Atchison and Holt Counties, Missouri on the left descending bank of the Missouri River between approximate river miles 516 and 522 with tieback levees along Rock Creek (upstream) and Mill Creek (downstream).

Figure 3. L-536 project location map



L-536 Levee Rehabilitation and Levee Setback

Conducted under the USACE's PL 84-99 levee rehab assistance authority between 2019 and 2022, the L-536 project is a premier example of a diverse group collaborating to accomplish a large-scale levee setback after one of the region's worst floods. The Missouri River levee system L-536 levee setback in Atchison and Holt Counties, Missouri involved USACE, Atchison County Levee District (ACLD), The Nature Conservancy (TNC), Natural Resources Conservation Service (NRCS), Missouri Departments of Natural Resources (DNR) and Conservation (MDC), and many other local, state, and federal agencies, as well as close coordination with five private landowners.

The priority under PL 84-99 is to restore the level of protection with the least cost, technically feasible alternative. The L-536 levee sponsor and surrounding community wanted to explore any and all options. One of the options was to conduct a levee setback around several levee breaches by leveraging state, federal, and NGO habitat conservation programs. A setback was estimated to be the option with the cheapest construction cost but would only work if the ACLD could find a way to secure over 800 acres of private land. Through discussions with USACE, TNC, and other partners, the ACLD and local landowners recognized this vision as the most forward-thinking, but it took several years of transparency, dedication, and endurance to see the project to fruition. A local community-based champion as demonstrated by the ACLD, a common vision endorsed by all partners, consistent communication through careful project management by TNC, perseverance and creativity by all were required to cobble together local, regional, and national authorities and resources for a successful outcome.

Initially, TNC played a neutral third-party role, organizing a multi-agency workshop in August 2019 to discuss partner roles and responsibilities. TNC hosted weekly team calls with more than 12 agencies for three years to coordinate design, construction, permits, real estate, weather delays, media requests, etc. These meetings became mini-workshops in interagency collaboration and conflict resolution. Prior to construction, ACLD,

Community-based local champions—members of the Atchison County Levee District.

Photo courtesy of Route3Films

Photo courtesy of The Nature Conservancy, B. Charry.

Some of the many partners and collaborators on the L536 projects

TNC, NRCS, and others led negotiations with landowners discussing their options for compensation, ultimately deciding on a course of action that would pay participating landowners pre-flood disaster farmland prices through voluntary sale of an easement utilizing the USDA's NRCS Emergency Watershed Program-Floodplain Easements program. After the easement is sold, the landowners continue to retain residual ownership interest in their land. All landowners who sold easements to the NRCS chose not to keep their residual interest in the land and that became a condition of the project moving forward. To address this landowner goal to divest of their ownership interest, a third party was needed to purchase the residual interest. TNC took on this role to purchase the residual interest, working closely with federal and state agencies as funding options were pursued. Potential project-ending real estate issues arose constantly, yet this team worked with county courthouses, surveyors, appraisers, and landowners to find solutions. Constant collaboration between ACLD, TNC, NRCS, MDC, DNR, and the State Emergency Management Agency ensured that willing seller landowners would be fully reimbursed in this voluntary program.

The construction costs for the setback portion of the project were approximately $100M, with the levee sponsor real estate costs for the levee setback footprint totaling approximately $700K. TNC spent an estimated $600K in staff labor, produced a short documentary[2], and developed a Levee Setback Playbook[3]. The State of Missouri provided nearly $1.6M in flood recovery grants to help purchase real estate. NRCS spent $2M in new conservation easements. Over $3.5M worth of existing conservation land under the USACE's Missouri River Recovery Program was leveraged for levee material and was converted to riverward floodplain habitat.

The completed L-536 project resulted in restoration of flood protection, a modern levee design built on more competent foundation, as well as the incidental creation of, and connection to, a Missouri River habitat complex now almost 7,000 acres in size with over 1,000 acres of land reconnected to the river. Over 420 acres of borrow pits used to excavate levee material were converted into depressional floodplain wetland habitats. They were given gentle side slopes, irregular banks lines, depth diversity, and in many cases were reseeded with native

2 http://bit.ly/3Oe0EHM

3 https://adobe.ly/3Efguxm

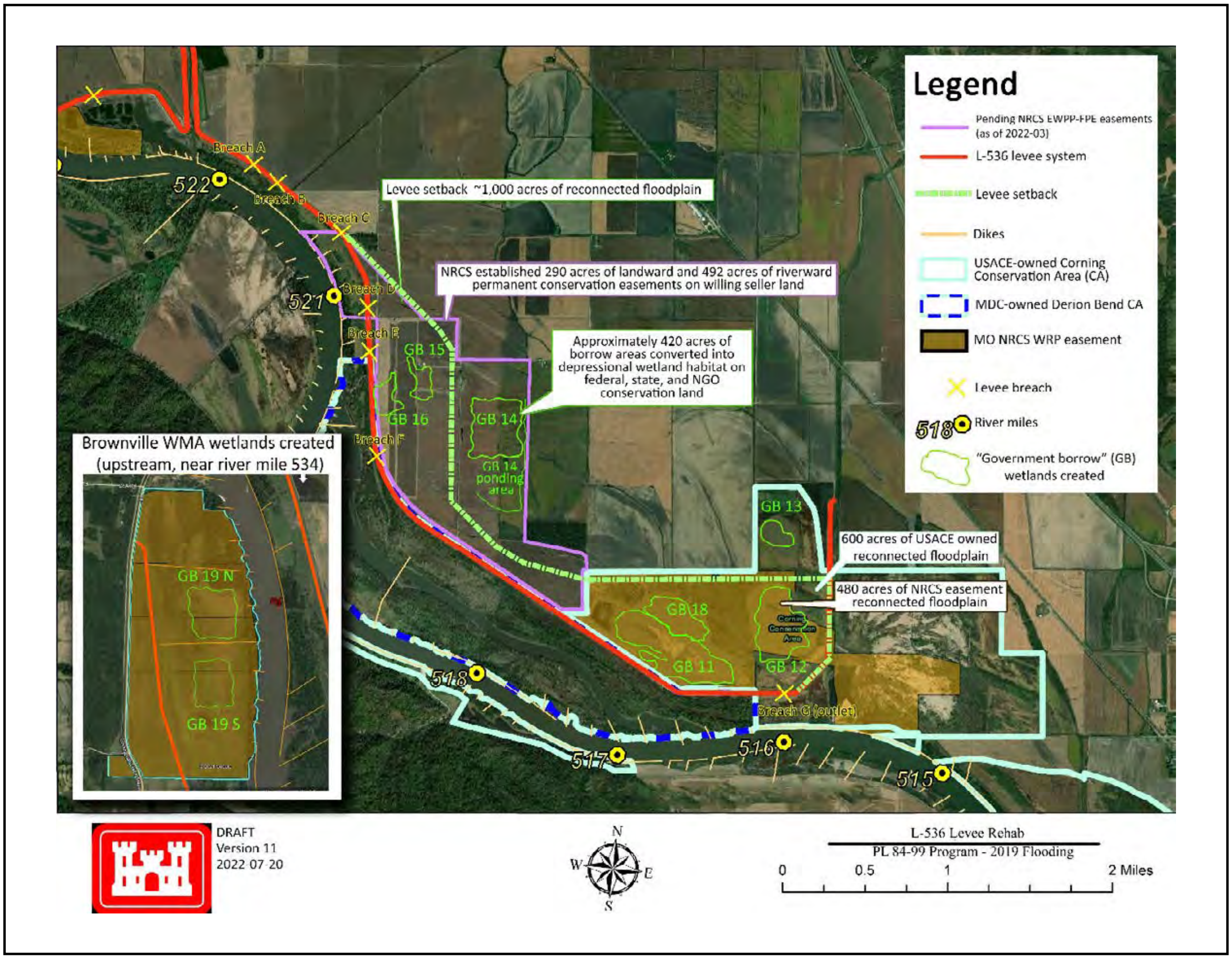


Figure 4. L-536 levee setback project and environmental features

wetland and/or mesic vegetation. Establishing strong partnerships with state, federal, and other conservation programs enabled the "borrow pit wetlands" to be located on conservation land where they can contribute to and help enhance the ecological function of the river-floodplain complex in the project area. The new wetlands, combined with the reconnected floodplain and the preexisting chute project in the area (Deroin Bend) is expected to result in increased waterfowl use of the area; increased production of macroinvertebrates on the floodplain during wet and dry years; increased floodplain access for fish and other aquatic wildlife for forage, refuge, and spawning during high water years; and possibly water quality improvement benefits as multiple agricultural drainage ditches now run through vast wetland complexes that can filter nutrients before the water enters the Missouri River. Aspects such as these will be targeted for monitoring and research in future years in an attempt to better quantify and understand these benefits.

Development of TNC's Large-Scale Levee Setback Playbook[4] will serve as a primer or guide to other drainage and levee districts and their respective communities as they contemplate how to adapt for flood resiliency while using nature-based solutions such as a levee setback. In addition, the Playbook will serve as an ongoing,

4 https://adobe.ly/3Efguxm

programmatic effort to institutionalize this level of creativity and collaboration for future projects. A Regional Memorandum of Understanding (MOU) between the USACE Northwestern Division and NRCS Central Region and pursuit of a novel NRCS policy waiver enabled the collaborative work at L-536. Updates to the Regional MOU are being considered to amend the MOU with lessons learned from L-536 and to serve as an example for collaboration between other USACE Districts and NRCS.

Future Research and Monitoring:

In mid-2022, the USACE's Engineering With Nature (EWN) program funded a USACE research taskforce focused on quantifying benefits of large-scale levee setbacks along the Lower Missouri River. As momentum and enthusiasm grew around the successes of the L-536 levee setback project, this initial research team began making connections with university research professionals (many also EWN-funded), other USACE research teams, and other state and federal agency researchers. Out of these early synchronization discussions was borne the concept that a levee setback research "Program" has essentially self-developed, and the efforts are in need of a cohesive vision. The end products of each effort should be developed such that they can also be leveraged by one or more other effort(s) and deliverables should be able to fit together like puzzle pieces. Integration of those separate efforts through an inter-disciplinary applied research program became informally solidified in late 2022. Collectively, these different efforts will seek to:

- quantify the environmental, socioeconomic, and flood risk management benefits of levee setbacks
- monitor previously completed setback projects and begin pre-project condition monitoring at potential setback sites (e.g., ground water quality and quantity, water quality improvements, wildlife use/production, fish access and benefits, etc.)
- elevate the awareness of nature-based solutions as a means to provide communities with flood resilience
- develop site selection and spatial prioritization tool for future levee setbacks
- facilitate local, regional, and Tribal stakeholder engagement with levee setback projects including but not limited to co-creating ways of working and approaches for implementation
- help advance the successful implementation of future levee setback projects with ecological and societal win-wins

Interim products from some of these research taskforces are already being incorporated into USACE planning efforts along the Missouri River, such as coordinating hydraulic analysis models and model outputs with the Lower Missouri River Flood Risk and Resiliency General Investigation Study team. Research teams associated with this "Program" are also actively collaborating with state and federal agency crews that conduct species monitoring and surveys near past and possible future levee setback projects in order to leverage each other's data. TNC, through its Mississippi River Basin 31-state initiative, is sharing information about this project with others in the basin while also incorporating information from other nature-based solutions for flood resiliency TNC projects into the design and thought processes utilized in levee setbacks. In addition, they are cataloging opportunities for engagement and change in the "three P's": policies, procedures, and practices as they pertain to nature-based solutions for flood resilience as well as supporting local champions willing to share their stories with other similarly affected landowners.

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A control structure directs flow and sediment from the main channel of the Missouri River at Searcy's Bend. This structure creates a side channel and shallow water habitat at Airplane Island next to the Overton Bottoms South Unit of the Big Muddy National Fish and Wildlife Refuge. This structure built as part of the Interception-rearing-complex Habitat Project.

The Formation of the Missouri River's Big Muddy National Wildlife Refuge (NWR)

by Tim Haller

Draining much of the earth's fourth largest watershed, the Missouri River (a.k.a. "The Big Muddy") has moved sediment to the sea for thousands of years. Once a shallow braided river with floodplain forests, marshes and wet prairies in the 1800s, today's waterway bears a heavy human footprint. Historically, the final destination of Missouri River sediment was the Mississippi River Delta where it built and sustained coastal wetlands. Today, after significant channelization and other alterations up and down the Missouri and Mississippi rivers all the way to the Gulf of Mexico, the life-giving sediment is washed to the ocean, and the coastal wetlands it once fed are disappearing at an alarming rate.

But water and sediment work together to create shallow water habitats where sediments consisting of sand, silt, clay and woody debris drops out of the waterway. During the time of Lewis and Clark's expedition in 1804, the river's floodplain provided the avenue for the creation

Photo courtesy of Big Muddy National Wildlife Refuge

of lush, productive habitat as it meandered across the river valley, creating thousands of acres of shallow water habitat including islands and braided channels where water velocity slowed. In its final 300 miles before reaching the Mississippi River, the Missouri River had nearly one million acres of floodplain to sustain this shallow water habitat during seasonal fluctuations. But this naturally occurring river flow process has been forever altered in the short timeframe of modern human history.

In the past 100 years, numerous dams constructed on the Missouri River and its tributaries have resulted in enormous impacts on the landscape and floodplain habitats. Marvels of modern engineering, the Missouri River Reservoir system and intensive engineering up and down both the Missouri and Mississippi rivers provides numerous economic benefits for human population, most notably the allowance of barge traffic. However, the effect of locking sediment behind the dams and thus stopping its journey to nourish the floodplain habitats and the Mississippi River Delta has been not only detrimental to coastal wetlands, but also to wildlife species that depend on these types of habitat.

The commercial navigation channel on the lower Missouri River created by the Bank Stabilization and Navigation Project alters the movement of sediment as well. Massive rock structures or revetments parallel to the river resist erosion of sediment. Additional rock control structures perpendicular to the river trap sediment and direct the flow. In Missouri, sediment accumulation associated with these structures created additional private land for many adjacent landowners. A system of federal and private levees further restricts the rivers ability to move and disperse sediment in its floodplain.

A National Academy of Sciences study (National Research Council, 2011) concluded that the loss of sediment resulted in reduced turbidity, changes in landforms and riverine habitat (shallow water habitat), river bed degradation below dams and on the main channel, and reduced sediment building in the Mississippi River Delta region.

Recognition of the negative impacts of the loss of sediment were further identified in the study, but mitigation efforts actually began much earlier than the formation of the Big Muddy NWR in 1994 with the passage of the Water Resource Development Act (WRDA) of 1986. This landmark WRDA bill passed by Congress allowed for the acquisition and development of lands to mitigate for habitat losses resulting from damming and channelization of the Missouri River. Subsequent passing of this bill enhanced this effort and funds from this bill are directed by the US Army Corps of Engineers (USACE).

Damages caused by the massive flood of 1993 and resulting aggressive sediment movement sparked many large-scale acquisitions from willing sellers through the WRDA. Lisbon Bottom in Howard County became a location where the river naturally attempted to bypass a bend during successive flood events in 1993 through 1997, creating a natural side channel of the Missouri River. Landowners whose cropland became shallow water habitat because of the flooding were facing cost prohibitive repairs or loss of use and were willing to sell. This river bottom became one of the first acquisitions of the Big Muddy National Fish and Wildlife Refuge (Refuge) created in 1994.

The Lisbon Bottom Unit as it is known today became an avenue for new discoveries in shallow water habitat. Juvenile pallid sturgeon, listed as

2016 oblique aerial view of the Lisbon and Jameson Island Units of the NWR. Lisbon is in the background and Jameson is in the foreground with the town of Arrow Rock to the left. Although the two chutes seen in the Jameson Island Unit were constructed, the braided mosaic through the trees provides an interesting representation of how the river would have historically created shallow water habitat.

Photo courtesy of U.S. Army Corps of Engineers

Photo courtesy of U.S. Army Corps of Engineers

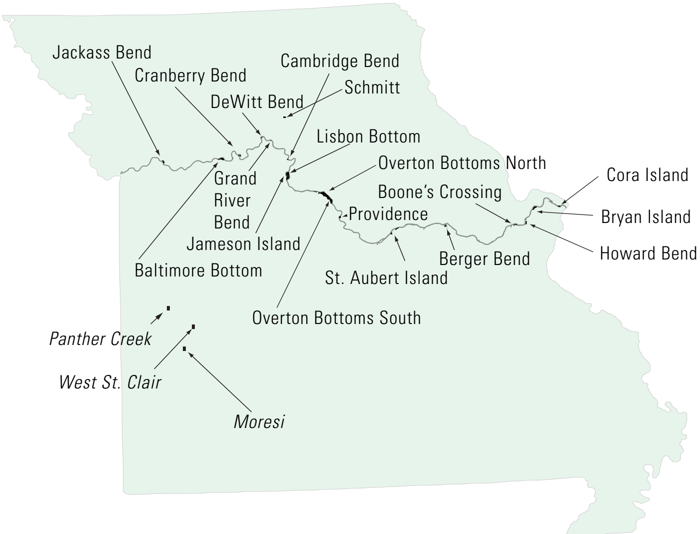
Shallow water habitat at Airplane Island. Sediment and debris drop out of the channel at this location because of rock control structures (seen in background) placed by the US Army Corps of Engineers as part of the Interception-rearing-complex habitat project. Low winter flows produce clear waters in the now sediment-starved Missouri River.

federally endangered in 1990, were discovered in this area after the 1993 flood, and at that time, biologists knew little of pallid sturgeon life history and habitat needs. Discoveries at the Lisbon Bottom Unit led to a better understanding of how juvenile pallid sturgeon use shallow water habitat to forage and escape predation.

Working closely with the USACE, the US Fish and Wildlife Service (Service) addressed the effects of stream revetments and channelization of the Missouri River Reservoir system and Bank Stabilization and Navigation Project to endangered species. The formulation of biological opinions from the Service helped the USACE establish the Missouri River Recovery Program (MRRP) (USACE, 2016).

The MRRP took some aggressive steps to help the river move sediment and replace shallow water habitat to benefit endangered species such as the pallid sturgeon. Several projects recreating side channels in the Missouri River were designed and created; many were on Refuge units. Monitoring of these channel projects have unfortunately proven the manmade channels are not as effective as the historic Lisbon channel at creating shallow water habitat. Some of these side channels were detrimental to maintaining the navigation channel and required the USACE to close them as they moved water and sediment in unpredictable ways.

More recent findings from research by the U.S. Geological Survey (USGS) focused the MRRP on creating Interception-rearing complex habitat (IRC). A less aggressive approach than building channels, IRC creates control structures that pull water along with drifting



Units of the Big Muddy National Wildlife Reserve as of 2022, totalling 21,929 acres. Map courtesy of U.S. Fish & Wildlife Service.

juvenile sturgeon from the main channel into braided channels of shallow water habitat for these juvenile sturgeon to thrive.

One such site known as the Searcy's Bend IRC is located on a large, established river sandbar near Huntsdale, Missouri. The sandbar, historically called Airplane Island, has been divided into three different sandbars separated by smaller channels. This site is adjacent to the Overton Bottoms South Unit of the Refuge.

Expect more of these IRC projects to occur on the lower river, especially on sandbars adjacent to the Refuge. Unfortunately, these IRC projects result in minimal amounts of sediment movement. Past MRRP projects that moved more sediment created controversy with private landowners, state agencies and challenges in maintaining the goals of the Bank Stabilization and Navigation Project while also assisting in flood mitigation and wildlife habitat goals.

The Refuge continues to grow along the Missouri River floodplain, and today is 21,929 acres, 36% of the congressionally approved 60,000 acres of habitat. Most of the Refuge consists of converted floodplain cropland where sediment from the Missouri River yielded successful crops for many years. Although the sediment will likely remain locked on the floodplain for another 1,000 years, the land is benefiting wildlife through the creation of floodplain forest, wet and tallgrass prairies, and the Big Muddy NWR helps mitigate flood water disbursement. Unfortunately, shallow water habitat remains a challenge to recreate under current conditions while also allowing safe passage for river traffic through the navigable water. Stretching along the Missouri River between Kansas City and St. Louis, these sections of floodplain and shallow water habitat have overall proven beneficial to wildlife.

The Big Muddy NWR is allowing the Missouri River to be a river again, to enter its floodplain. This occurs during minor flood events. Management has created side channels, cut down levees, and allowed the floodplain vegetation to return naturally. Currently, in many places, the refuge is an impenetrable thicket of young trees and vegetation, but, as the trees grow and the refuge matures, its appearance will undoubtedly change. The process may take decades or even centuries. Hopefully through time, science and the unpredictable nature of the river will further lead to discoveries making the "Big Muddy" just a little muddier.

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Photo by Valerie Hentges

Year-old pallid sturgeon awaiting release into the Missouri River.

Past Leading Our Future on the Missouri River for the Pallid Sturgeon

By Valerie Hentges

The state of Missouri can provide a large range of recreational activities. For many of us, at least one major recreational activity we enjoy revolves around water. Water is a lifeblood to so many aspects within our lives, especially in the state of Missouri, since it has over 100,000 miles of streams and rivers. Over 2,300 miles long, the Missouri River is the longest river in the United States. Its headwaters start on the southwestern side of Montana and flows through and borders multiple states. The Missouri River Basin spans ten states, over 20 different Tribal lands, a small portion of Canada. Over 10 million people live around the river basin, and many fish and wildlife species, including the pallid sturgeon, inhabit the Missouri River. At its confluence with the Mississippi River (near St. Louis), the Missouri and Mississippi rivers become the world's fourth largest river system.

Rivers continue to link our natural environment and our human interests together. As the United States grew with the Louisiana Purchase, President Thomas Jefferson saw the mouth of the Missouri River as an area of opportunity to explore the West and to reach the Pacific Ocean—hence, Lewis and Clark's expedition on the Missouri River. In May 1804, they started the "Corps of Volunteers for Northwest Discovery" (i.e., Corps of Discovery) with the overarching goal to discover commercial opportunities. President Jefferson requested funding for the expedition from Congress, but reportedly did not mention that an underlying reason for the trip was also for scientific discoveries.

Lewis and Clark prepared for months prior to starting their journey, educating themselves, gathering supplies and trade items and selecting their crew. The beginning of their journey was not easy, nor was any part easy. During the first winter of the Corps of Discovery, they decided to camp (creating Fort Mandan) downstream along the Missouri River streambanks in North Dakota. The friendly Mandan and Minitari Tribes also became a reason to stay in the area. While here, Lewis and Clark hired a French-Canadian trapper and his pregnant Shoshone wife, Sacagawea, to join them. After an arduous journey through the Rocky Mountains, with the assistance of Sacagawea in many key aspects, they successfully traveled other rivers ultimately achieving the expedition's goal of reaching the Pacific Ocean. Their journey back East sometimes took a slightly different path to explore a possibly better route, or other rivers. By late September 1806, the Corps of Discovery completed their commercial opportunities and gained lots of scientific knowledge.

Today, Congress continues to direct the administration of programs on the Missouri River and now it is the U.S. Army Corps of Engineers (Corps) working with partners on programs such as flood risk resiliency, navigation, irrigation, impounding, channelizing, and dredging. The headwaters of the Missouri River in Montana remains relatively unaltered. The middle portion between Montana and South Dakota became mostly reservoir systems allowing for water storage and hydropower needs. The lower portion of the Missouri River is channelized into a deep, narrow channel maintained to allow for navigation. Many of these alterations have impacted the fish and wildlife that depend on the Missouri River for habitat and survival.

The Corps maintains different programs that help mitigate the effects of river management on wildlife and property including one that will ultimately mitigate for roughly a third of the loss of over 500,000 acres of fish and wildlife habitat from Sioux City, IA, to the confluence with the Mississippi River, 735 river miles. The Corps continues to work with willing landowners along this stretch of the Missouri River (through NE, IA, KS, MO) towards their authorization of 166,750 acres of fish and wildlife mitigation lands. Land purchased by the Corps and restored for fish and wildlife habitat, including levee setbacks, are examples of possible mitigation efforts becoming a win-win for all parties involved. The Corps also implements the Missouri River Recovery Program (MRRP) to comply with the Endangered Species Act, while allowing for benefits for commercial interests to continue. Working with the U.S. Fish and Wildlife Service (Service) through the Endangered Species Act, the Corps and Service use the MRRP biological assessment and biological opinion as guiding documents, plus other accompanying scientific documents. To achieve program goals, the Corps works in partnership along with other Federal and state agencies, Tribes, non-profit organizations, and stakeholders along a portion of the Missouri River. These documents help guide the recovery efforts of the federally listed threatened and endangered species due to the Corps action on a portion of the Missouri River. Like Lewis and Clark, the Corps of Engineers, through the MRRP, conducts scientific studies of listed species such as the pallid sturgeon, which ultimately leads to actions to mitigate the decline.

The pallid sturgeon is a unique species whose ancestors inhabited the rivers thousands of years ago. They are a long-lived fish that are native to portions of the Missouri and Mississippi rivers and several major tributaries. Often described with having a prehistoric appearance, they thrive with their fellow fish in the scientific family of *Acipenseridae* (which includes the shovelnose sturgeon) as benthic feeders. Fish of this family prefer rivers that maintain high turbidity with a natural hydro-

Photo credit: Wayne Nelson-Stastny

A pallid sturgeon ready to be released back into the Missouri River after a health assessment and radio telemetry tag inserted into its body. The radio transmission wire is located around their stomach area and does not cause any health consequences to the fish.

graph, a diversity of depths and velocities, braided channels, sand bars, and gravel bars. Fortunately for a pallid sturgeon, all of these characteristics were the historic features of most of the Missouri and the lower portion of the Mississippi rivers. While Lewis and Clark's expedition began the Western expansion through river exploration, it was not until the end of the 1800's when the active management of the Missouri River began for the benefit of human needs and development. Habitat alterations such as channelization, impoundments and reservoirs, altered flow regimes, decreased water quality, entrainment, climate change leading to water temperature changes, development in and on the Missouri River leading to habitat fragmentation, and overutilization and overharvest (due to the similarity to federally listed threatened shovelnose sturgeon) are some of the factors the Service determined as contributing factors leading to the pallid sturgeon declines we witnessed in the 1990s. On September 6, 1990, the Service determined the pallid sturgeon was imperiled and was listed as a federally endangered species under the Endangered Species Act. This dinosaur-like fish has existed since prehistoric times, and together we have a responsibility to ensure it exists long into the future. That is our path of 'discovery.'

The pallid sturgeon possesses a unique anatomy that separates them from most other fish; most other fish have skeletal bones, but pallid sturgeon have a cartilaginous skeleton like a shark and protective bony plates called scutes. Their long, pointed snout adds to their torpedo-like body shape allowing them to maneuver through strong, swift river currents, or helps to anchor them on the riverbed. The pallid sturgeon mouth is positioned on the bottom of their head to gather food such as larval aquatic insects when the fish are juveniles, but as adults, pallid sturgeon add fish to their diet. Because of the highly turbid river habitat they live in, pallid sturgeon rely more on scent and touch to discover prey rather than vision. As an adult, a pallid sturgeon can reach

Photo by Valerie Henges

Field crews search the Missouri River for radio-telemetry-tagged fish to conduct health assessments and gain further insight into the species.

Photo credit: Wayne Nelson-Stastny

In the upper portion of the Missouri River, field crews insert a radio telemetry tag inside key pallid sturgeon to allow for tracking and further scientific studies.

up to six feet in length and weigh more than 50 pounds. Under optimal conditions, a male typically becomes reproductively mature around 10 years old. On the other hand, a female will become reproductively mature between 15 and 20 years old. When river conditions signal the suitable conditions, spawning may occur after reproductively-ready males and females travel as much as several hundred miles for the suitable conditions of habitat. Females spawn typically every two years in the suitable habitat conditions; otherwise, they will reabsorb their eggs. Alternatively, adult males can spawn every year. Once successful spawning and egg hatching occurs, the larvae will freely drift down river for approximately a week, literally going with the flow for hundreds of river miles. After their drifting stage is complete, they will settle down to the bottom of the river to eat and grow as juveniles. Unfortunately, this endangered species needs a little help with their reproductive cycle due to their low population, the female's natural reproductive cycle, and altered river conditions that include water flow levels, water temperatures, available habitat, and male and female aggregations.

On the Missouri River, several federal and state agency field crews help keep a pulse on the pallid sturgeon. Field crews use a telemetry network to help track and locate tagged pallid sturgeon. With the help of this telemetry network and the skills of the field crews, each year the propagation program receives new sturgeon for propagation or fish that are new to the propagation program to increase a specific fish's genetic diversity. Currently, the Service's hatcheries that support the pallid sturgeon propagation program include Gavins Point National Fish Hatchery in Yankton, SD; Garrison National Fish Hatchery in Riverdale, ND; and Montana Fish, Wildlife and Park's Miles City Fish Hatchery in Miles City, MT.

At these hatcheries, fish biologists care for pallid sturgeon at various stages of life for a

specific purpose. An adult pallid sturgeon is normally brought into the hatchery as part of the broodstock program for a future hatchery spawning event. After caring for the fish that should be ready to spawn in the late spring or early summer, biologists carefully spawn females in the hatchery. In their natural setting, females will release a group of their eggs every several hours, ultimately releasing around 20,000 eggs, depending primarily on the size of the fish. If a new male pallid sturgeon is brought into the hatchery, biologists will also spawn the males. When 'extra' milt is available after the hatchery spawning event, it is added to the repository for future use to diversify the genetics within the population during a future hatchery spawning event.

After a successful hatchery spawning, the fish biologists care for both the fertilized eggs and the recently spawned adults. Depending on the objective of the spawning, some of the pallid sturgeon embryos, larvae, juveniles, and yearlings will be stocked into the Missouri River at different times and life stages. The rest are used during carefully-crafted scientific research laboratory studies to increase our knowledge of the species. When an embryo stocking event occurs, it is another learning experience wherein the field crews help determine fish drift distance downstream. When the field crews take a genetic sample of the fish, along with physical markers on each year's fish stocking events, it assists in determining if they were spawning in a hatchery or naturally in the wild. Since females need 15 to 20 years to become reproductively mature, the ultimate success of a single stocking event may not be known until that time. In a large river system like the Missouri River, it can be difficult to locate an endangered pallid sturgeon until they are adults and move more as an active reproductively mature fish. Having habitat that supports them throughout their lives, but also

Photo by Valerie Hentges

Fertilized eggs from a hatchery spawning event are carefully monitored to ensure their success.

Photo credit: Wayne Nelson-Stastny

Pallid sturgeon, a couple weeks old, in holding tanks as they grow and develop at the hatchery.

in the critical stages of their growth, is one key to the recovery of this endangered species.

Habitat for any species is the key to survival. For the pallid sturgeon, because the riverine habitat has been significantly altered in the last century and a half, we can help to improve their habitat in the Missouri River. Such projects to improve sturgeon habitat was recently completed in a levee setback in Atchison Co., Missouri. In this newsletter, one can read more about the levee setback projects that began after the 2019 flood that left damages on 56,000 acres, 14 commercial businesses, and over 150 homes flooded; an estimated $25 million lost in agricultural production; major state highways closed and damaged; train travel interrupted. Ecologically, levee setbacks such as this one returns floodplain habitat for fish and wildlife, which translates to more spawning habitat options and early life stage habitat for newly hatched to juvenile fish. Physical habitat is one aspect that can be improved, enhanced, and restored as part of the federal program as shown in the project in Atchison County.

The existing physical barriers to habitat connectivity are another concern that the Corps, Service and other partners continue to address. As an example, on the Yellowstone River, a major tributary to the Missouri River in Montana, another major partnership recently completed the construction of the 'Intake Bypass Channel' which allows for both the continued benefit of water diversion for agricultural purposes and the construction of a side channel around the diversion dam allowing for pallid sturgeon and other fish passage further upstream. This project created a passage that was closed to fish for roughly a century. From April through October 30, 2022, 18 radio-tracked pallid sturgeon successfully used this bypass channel to continue their migration upstream to the suitable spawning habitat that allows sufficient drift distance for developing larval pallid sturgeon. This creation of the bypass channel on the Lower Yellowstone River opened 165 miles on the mainstem Yellowstone River, plus 20 miles of the Tongue River and over 150 miles on the Powder River, which are major tributaries to the Yellowstone River, all now open to pallid sturgeon. All of these rivers also feed the Missouri River. Many of the recovery efforts (like the Intake Bypass Channel) on the Missouri River for endangered species can succeed only with an extensive amount of time, and financial and stakeholder support within a strong and diverse partnership.

The pallid sturgeon's extensive range requires the Service to develop partnerships working with many Federal, Tribal, and state agencies, university researchers, non-profits, and stakeholder groups as we reach towards pallid sturgeon recovery goals through robust scientific programs. Since the ESA listing in 1990, available funding has allowed biologists to learn more about this charismatic fish's life history and habits. However, there remain many different aspects of their life history that need exploration—or further exploration—to achieve the successful recovery of the pallid sturgeon within our nation's largest river system, while also maintaining the many benefits humans reap from this great river system.

When there are sufficient numbers of pallid sturgeon from natural spawning events in the Missouri River for two generations to sustain populations, the recovery goal will be met. Since the Missouri River has been modified for the benefit or protection for human life aspects, the recovery of the pallid sturgeon will continue to be integrated into these human needs. We must all work together to gain a deeper understanding of our needs as a society and the needs of our fish and wildlife resources, for current and future generations to marvel a fish species that has been in our Missouri River since prehistoric times.

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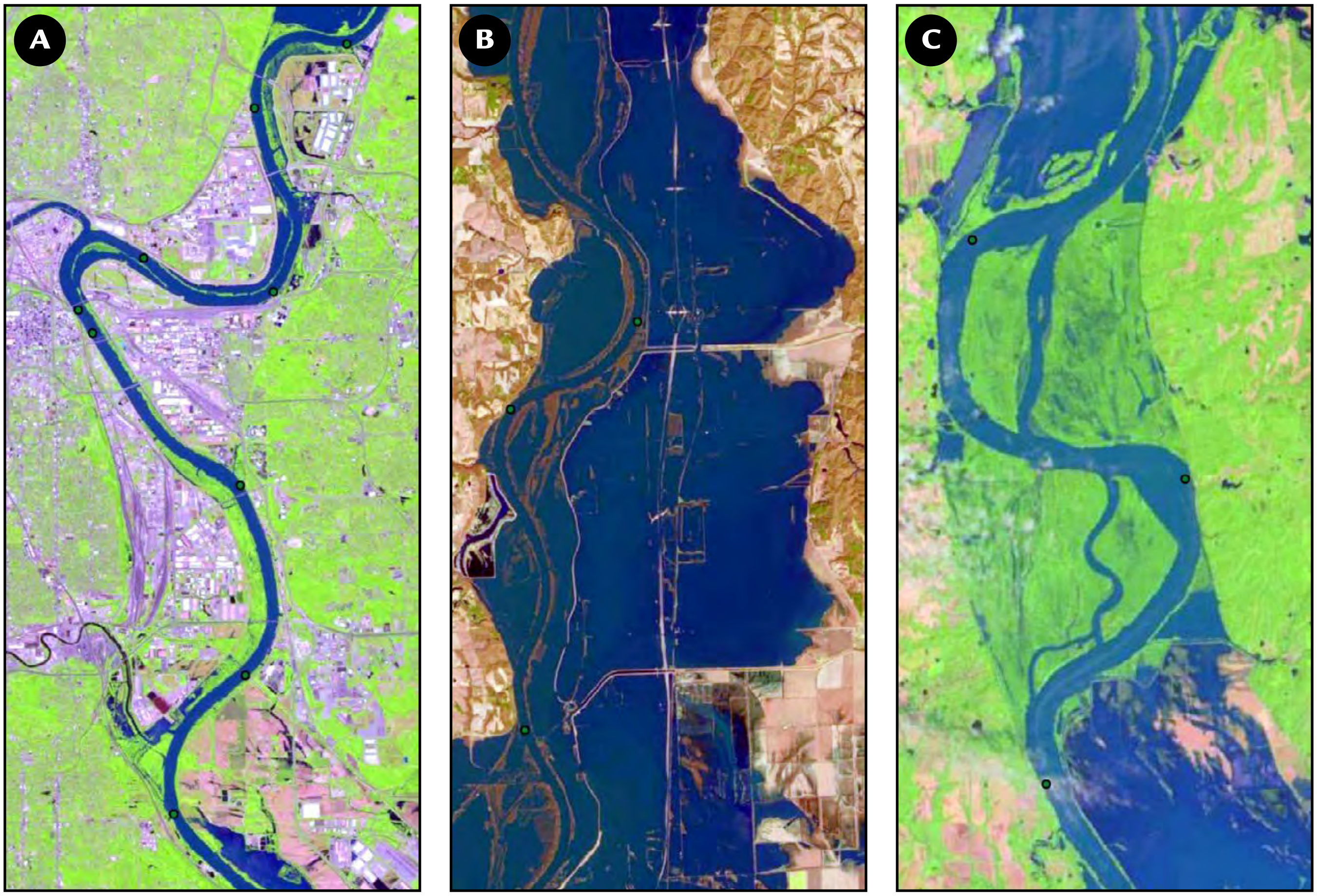


Images from Copernicus Sentinel data 2019 for Sentinel data. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Figure 1. Examples from the 2019 flood on the Lower Missouri River showing three types of resilience. A. Kansas City, Missouri, area with high engineering resilience. B. Lisbon Bottom and Jameson Island units of the Big Muddy Fish and Wildlife Refuge near Arrow Rock, Missouri, area with high ecological resilience. C. Agricultural land near Bartlett, Iowa, showing lack of resilience in areas with overtopped levees, flooded agricultural fields, and flooded transportation infrastructure.

Common Ground: Flood-risk Reduction and Conservation in Large-river Floodplains in Missouri

By Robert Jacobson, Ph.D.

Introduction

Extreme floods between 1993 and 2019 along the Missouri and Mississippi rivers have motivated questions about whether there may be alternative ways to live and work along these rivers to reduce flood risks and increase net benefits to society. These ideas can be evaluated in the context of resilience, the property of being able to bounce back after flood damages. Resilience can be achieved by minimizing the damages in the first place, or by increasing the recuperative properties of the floodplain ecosystem, or both.

The ecological literature differentiates between engineering resilience and ecological resilience (Gunderson, 2000). Engineering resilience minimizes damages to floodplains and adjacent communities by containing floods with levees or floodwalls (Figure 1). However, when engineered structures fail to contain a flood, damages can be extensive. In addition to inundation damages to structures or crops, discharge of floodwaters through levee breaks

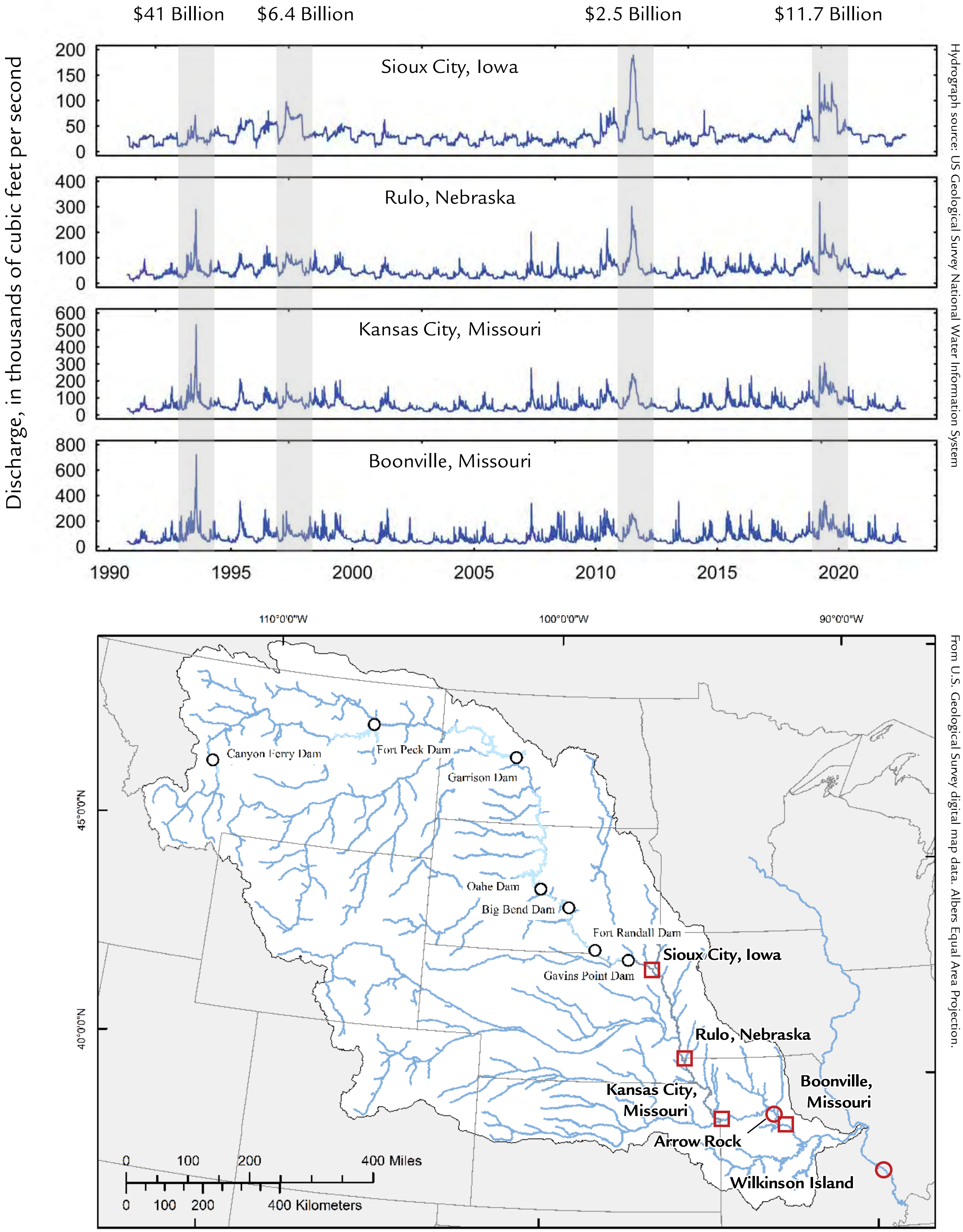


Figure 2. Top: Flood history of the Missouri River since 1990 showing the 4 "billion-dollar" floods (NOAA, 2022). Dollar amounts of the 1993 and 2011 floods include damages on the Mississippi River. **Bottom:** The map shows dams (black circles), stream-flow gaging stations (red squares), and locations referenced in the text (red circles).

focuses velocities and shear stresses, which can result in deep scours, extensive sedimentation, and damages for which repair costs exceed benefits (Jacobson, 2003; Londoño and Hart, 2013).

Alternatively, the concept of ecological resilience accepts that floods will cause changes to a floodplain ecosystem through erosion, sediment deposition, or long-duration inundation that may damage vegetation communities. In ecological resilience, the ecosystem absorbs the flood-induced changes and recuperates (Holling, 1973; Bouska and others, 2018). Moreover, flooding may be beneficial to a floodplain by importing nutrients, providing access to floodplain-spawning fishes, facilitating forest regeneration, and providing seasonal wetland habitats. Indeed, some of the flooding effects may have quantifiable benefits to society by providing ecosystem services like carbon storage, denitrification of floodwaters, flood-stage reduction, and hunting and fishing opportunities.

The high costs of recent floods—including some in the last 30 years that have qualified for the billion-dollar disaster list (Figure 2)—have been concentrated in rural areas rather than developed areas. This is because levees in rural areas have generally been built to lower and more variable protection levels compared to those near urban areas. In rural areas, especially, recurrent levee breaks have prompted consideration of alternative levee designs in which alignments are moved away from the river (levee setbacks), giving the river room to spread out during floods (The Nature Conservancy, 2021b). The prospect of levee setbacks along the Missouri River has motivated new research into how such setbacks may define common ground between flood-risk reduction and conservation. This article explores several key concepts related to scientifically informed floodplain management alternatives, using the Missouri River as an example.

Background

The Missouri River drains an area equivalent to 1/6 of the United States, extending from St. Louis, Missouri to the continental divide in Montana. As a result, floods of the Lower Missouri River arise from diverse sources, including snowmelt from the Rocky Mountains and precipitation from tropical air masses from the Gulf of Mexico. Floods arising upstream from Gavins Point Dam, South Dakota, can be mitigated by 5 large reservoirs in the mainstem reservoir system whereas downstream runoff is much less controlled by flood-storage reservoirs. The 1993 flood, for example (. 2) arose from tropical airmasses that migrated north from the Gulf of Mexico to Kansas, Missouri, and Iowa in July and August of that year; little of that resulting runoff was intercepted by the Missouri River mainstem flood-storage reservoirs. In contrast, the floods of 1997 and 2011 were dominated by melting of snowpack in the Rocky Mountains and Great Plains and were partially contained by the mainstem reservoir system. Flooding from 1997 and 2011 was substantial just downstream from Gavins Point Dam but because little additional runoff was added as the flood moved south, the relative size of those floods decreased downstream (Alexander and others, 2013).

Floods on the Lower Missouri River interact with a channel and floodplain that have been extensively altered from the natural condition. Channelization and stabilization of the Missouri River resulted in a narrowing of the channel and loss of 404 km² of aquatic and 274 km² of sandbar habitat as land was accreted to the banks (U. S. Army Corps of Engineers, 1998). This loss of within-channel habitat resulted in an increase in floodplain habitat as land was accreted to the banks, but levee construction disconnected most of the new and pre-existing

floodplain from the river. The extent of levee protection varies along the river. From the confluence with the Mississippi to just upstream from Omaha, Nebraska, levees adjoin most of the river with average distance between the levees (or measured between levee and bluff if one side is unleveed) being 1,036 m. Many areas—so-called pinch points—are even more constricted, with distances reduced to as little as 300–500 m (Jacobson, 2017; Jacobson and others, 2022). The present state of levee constriction contrasts with the original concept for flood-risk reduction that envisioned a flood corridor of 4,000–5,000 feet (1,220–1,514 m) from Kansas City to St. Louis, Missouri and 3,000 feet (914 m) upstream from Kansas City (War Department, 1947). This recommended floodway width equates to about 4 times the modern channel width. The floodway concept was not enforced over most of the river length as private levee districts built levees to maximize land area available for agricultural production. In contrast to the Missouri River, the Lower Mississippi River (downstream from the Ohio River confluence) mainline levees are spaced to provide a flow corridor on average about 10.4 kilometers wide, or about 6.5 times the average channel width (Biedenharn and others, 2018).

Concepts

FLOOD RISK

Recently, water management agencies have shifted their vocabulary from "flood control" to "flood-risk reduction" (Tullos, 2018). This language recognizes that water-management projects are unlikely to eliminate all damages from floods, regardless of designs. The risk-based concept stands in contrast to the name of the enabling legislation for the Missouri River mainstem dams: "The Flood Control Act of 1944" (U.S. 78th Congress, 1944). Contemporary (1944) public relations literature published by the US Army Corps of Engineers asserted "Flood protection and river regulation reservoirs and localized protection works now authorized by Congress will assure protection for over 2,000,000 acres of agricultural land and many communities in the Missouri River basin." (U.S. Army Corps of Engineers, 1947). In contrast, the concept of flood risk conveys the gradational and probabilistic nature of flood threats.

Flood risk can be quantified simply as the product of hazard and exposure (Tariq and others, 2020):

$$\mathit{Risk} = \mathit{Hazard} \times \mathit{Exposure}$$

where Risk is usually given in units of dollars of damage per year, Exposure is given in value of crops or structures on the floodplain that would be lost if flooded, and Hazard is the probability per year that the crops or structures would be flooded. Risk can be decreased through either decreasing hazard or decreasing exposure, or both. Hazard, for example, can be decreased through reservoir management strategies that limit floods or by building high levees. Exposure can be reduced by removing vulnerable properties, commodities, or infrastructure from the floodplain. Whereas exposure is usually considered a negative quantity, as in crop loss or damages to structures, consideration of ecosystem services associated with flooding (nutrient mitigation, provision of waterfowl habitat, for example) can add in positive quantities that may mitigate damages and change the calculated annual risk. This type of calculation would fundamentally define the common ground of conservation lands in floodplains.

FLOOD ELEVATION AND FLOOD ATTENUATION

One of the important ecosystem services attributed to connected conservation lands in floodplains is regulation of floods. Connected floodplains allow floodwaters to spread out

over a larger area than if they were constricted by levees, resulting in two possible net effects. The first expected benefit is lowering floodwater elevations, which is apparent through simple conservation of mass: for a given discharge of floodwaters, a wider flow results in lower local elevations. Although this hydraulic effect is likely, it can also be counter-balanced when floodplain vegetation induces increased drag (roughness) on floodwaters, decreasing water velocity on the floodplain. Hydraulic modeling of connected, unleveed floodplains on the Missouri River indicates that vegetation-induced roughness can substantially eliminate decreases in water surface elevations gained by increasing floodplain flow width, especially when flow is through young, dense stands of willows and cottonwoods (Jacobson and others, 2015). Researchers of large-river floodplain restoration in Europe have determined that floodplain restoration with wet prairie communities maximizes ecosystem services like biodiversity and provision of habitat for pollinators while minimizing hydraulic roughness (Straatsma and others, 2019).

Vegetation-induced hydraulic roughness also interacts with floodplain sedimentation because rougher floodplains slow velocities, which can result in deposition of sediment from suspension. A levee setback area at Wilkinson Island in the Middle Mississippi River near Raddle, Illinois (Figure 2) is a recent example in which as much as 4 m of sedimentation was recorded over a thirteen year period in a unit of the Middle Mississippi US Fish and Wildlife Refuge (Remo and others, 2018). These high rates of sedimentation were considered detrimental to bottomland hardwood communities.

A second flood-risk reduction benefit often attributed to reconnected floodplains is flood attenuation. Attenuation is defined as temporary storage of floodwaters on the floodplain—much like a reservoir—with the result that magnitudes of downstream flood peaks are decreased and duration of flood are increased as water is slowly released from the floodplain. Attenuation theoretically has cumulative downstream benefits whereas flood elevation decreases only apply to the reach where the floodplain is reconnected or slightly upstream and downstream. In a modeling assessment of a 10-year return flood (1 in 10 annual return probability) on a 2,000 hectare area of the Missouri River floodplain, attenuation was not measurable although some evidence indicated potential for attenuation of smaller, more frequent floods (2-5-year return interval) (Jacobson and others, 2015). Re-connected floodplains do not attenuate large floods because the available floodplain storage area fills up and conveys water on a shorter path and almost as efficiently as flow in the main channel.

NON-STATIONARITY

Non-stationarity is a term used by statistical hydroclimatologists to describe systems with temporal trends. Whereas all time series of hydrologic and climatic data show great variability within- and among-years, non-stationarity is identified when the average conditions are changing substantially over time. Non-stationarity has important implications for water resources engineering because the design of reservoirs, levees, flood walls, and other water features is dependent on calculations of how big and how often large flows occur. With the realization that climate change is affecting time series of hydroclimatic events, some scientists declared that "stationarity is dead," with the implication that designs based on past data are no longer viable for long-term engineering resilience (Milly and others, 2008).

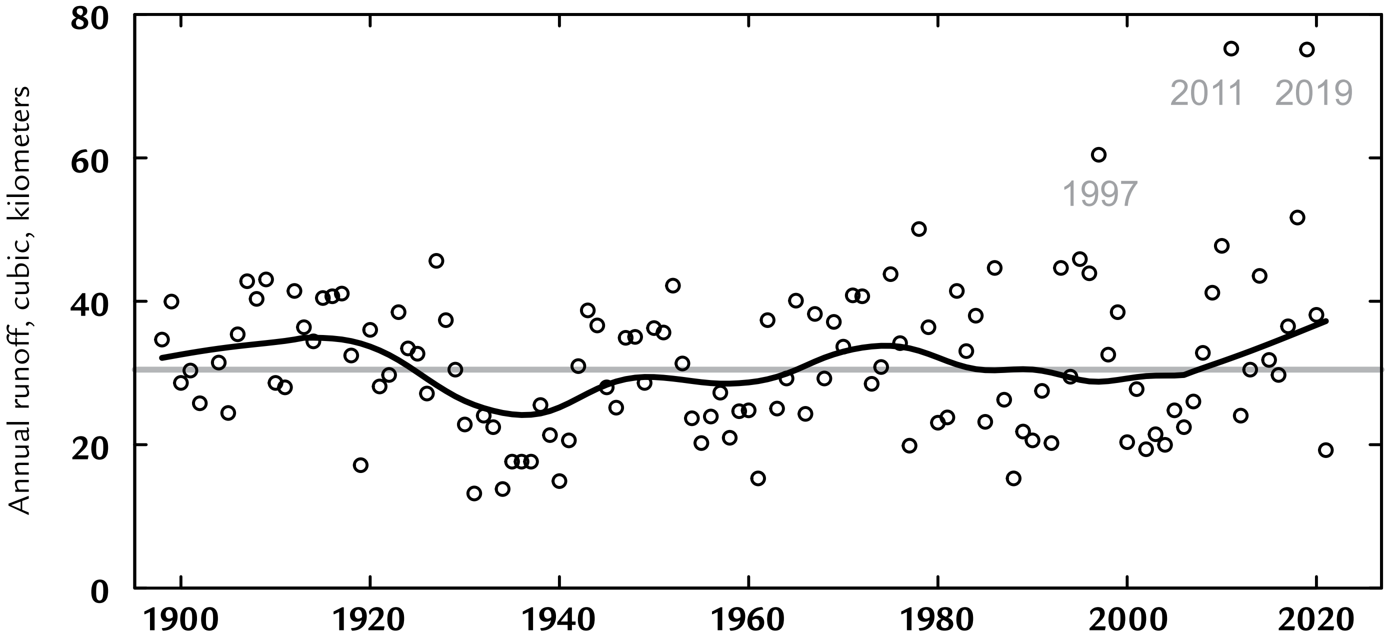


Figure 3a. Annual runoff upstream of indicated streamgage in cubic kilometers. The black line is a locally weighted regression (LOWESS) smoothing function using a span of 25% of the data. The gray line is the median of the runoff for the indicated period of record. Runoff into the Missouri River mainstem reservoir system at Gavins Point Dam, South Dakota, 1898 - 2020; source: US Army Corps of Engineers, Missouri River Water Management.

Non-stationarity has been challenging to identify in many hydrologic records because of natural variability (Norton and others, 2014). On the other hand, global and regional climate models have consistently predicted warmer conditions, with more moisture in the atmosphere, greater probability of intense runoff events, and greater annual variability of runoff in the midcontinent United States (U.S. Bureau of Reclamation, 2014; Jacobson and others, 2022). With longer records and a focus on annual runoff, non-stationarity is now apparent in the record for the Missouri River (Figures 3a & 3b). The data document increasing magnitude of wet years and increasing year-to-year variability. The convergence of predictions from climate-change models and the trends in the empirical record indicate that flood hazards are likely to increase on the Missouri River. The net effect on flood risk will depend on whether exposure increases or decreases.

Floodplain natural lands

Two types of conservation development have been pursued in the Missouri River valley. One type—the so-called "beads on a string"—describes when an entire floodplain "bottom" is converted to conservation management. The other type is a levee setback, the situation where the floodplain area connected to the river is increased by moving the levee back from the river but much of the land is retained in agriculture.

BEADS ON A STRING

Presently, there are approximately 24,000 hectares in public land in the Missouri River valley bottom bordering and within the state of Missouri. Ownership is shared among the Missouri Department of Conservation, Missouri Department of Natural Resources, U.S. Army Corps of Engineers, Nebraska Game and Parks Commission, and the U.S. Fish and Wildlife Service. Using the Big Muddy National Fish and Wildlife Refuge as an example, some units man-

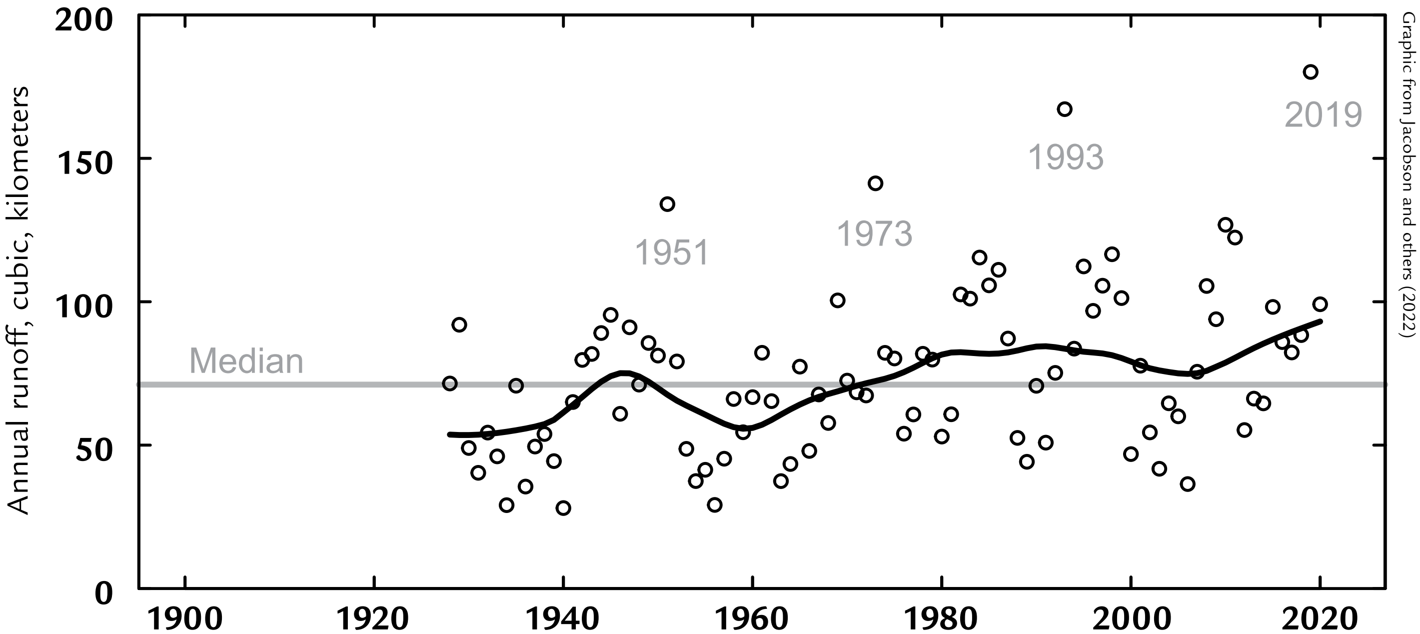


Figure 3b. Runoff upstream from Hermann, Missouri; source: US Geological Survey National Water Information System.

aged by the Refuge encompass entire bottoms, or most of the bottoms (for example, Lisbon Bottoms and Jameson Island near Arrow Rock, Missouri). In these situations, the managing agency has the ability to naturalize the lands without direct concerns for negative interactions with neighboring landowners. In particular, if the agency owns the land and the levee district, the agency can breach levees or leave them unrepaired to promote passive restoration, which is often a least-cost alternative. Opening entire valley bottoms to flooding provides benefits to neighboring bottoms by spreading out the floodwater and lowering water-surface elevations. As noted above, these areas may also attenuate floodwaters during floods with 2–5-year return intervals.

PROSPECTS OF LEVEE SETBACKS

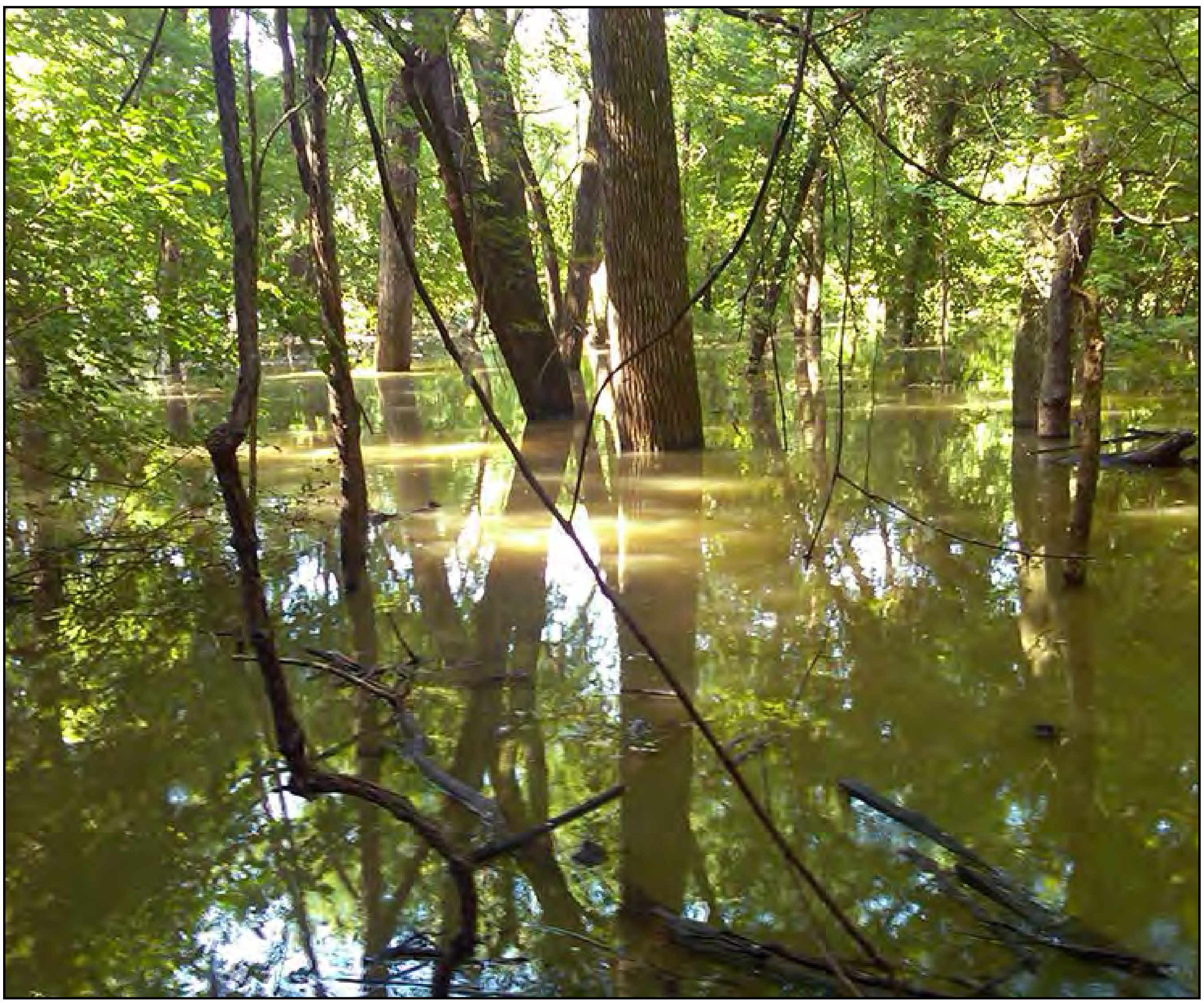
Levee setbacks have been promoted as a mechanism to increase ecosystem services and decrease flood risk among large rivers like the Missouri and Mississippi (Dierauer and others, 2012; Dahl and others, 2017; Smith and others, 2017). Levee setback concepts have been used in planning for several decades in the European Union in the "room for the river" approach (Piégay and others, 2005; Rijke and others, 2012). For local landowners, a setback may be seen as a means to achieve a solution with greater engineering resilience after years of fighting floods (The Nature Conservancy, 2021b). Setbacks serve to naturalize land on the riverside of levees, potentially creating a continuous riparian corridor. The design objective is to provide the same or higher protection level for land and infrastructure landward of the levee. Unlike when whole valley bottoms are naturalized, setbacks require engineering designs that increase natural processes while also protecting levee integrity. The idea that setbacks could achieve greater engineering and ecological resilience has taken hold and pilot studies are now under way at multiple sites along the Missouri River (Krause and others, 2015; The Nature Conservancy, 2021b, a).

Several fundamental considerations underlie decisions about levee setbacks.

- Cost is a prominent factor. For example, the levee setback in Atchison County in Missouri (L-536), which added 405 hectares of connected floodplain, cost as much as $103 million for 6.9 kilometers of levee reconstruction (The Nature Conservancy, 2021b, a). At a per-kilometers cost of $15 million, extension to a substantive proportion of the 960 kilometers of leveed distance along the Missouri River results in estimates of billions of dollars to protect mostly agricultural land. Benefit:cost assessments of similar projects may be improved by adding the ecosystem benefits that such projects may provide to the value of damages averted (Figure 4). Recent calculations, for example, have documented that Missouri River floodplains have the potential to provide conditions for substantial denitrification of floodwaters, albeit in small amounts relative to the annual flux of nitrogen in the river (Jacobson and others, 2022).
- Related to cost is the question of ownership and revenue from lands between the river and the new levee alignment. Conservation land in public ownership provides ecosystem services and can provide recreation rev-

Figure 4. Flooded conservation land along the Missouri River near Columbia, Missouri.

Photo credit: Robert Jacobson, U.S. Geological Survey



enue (Treiman and others, 2014) but there is frequently concern that public lands are taken out of production and consequently lower the local tax revenues (Prato and Hamed, 1999). Many of the lands between the levees in the Lower Mississippi River have alternative, revenue-producing uses such as timber production, hunting leases, and biofuels, which could be considered in overall benefit:cost assessments.

- Given the high cost of levee setbacks, prioritization of location and sequence is a factor. "Pinch points" at levee constrictions have been identified as potential priority locations for new setbacks (Krause and others, 2015). In addition, U.S. Geological Survey assessments have identified zones along the river where the channel is aggrading or has minimal incision, and where as a result levee setbacks would be most effective in providing connected floodplain habitats (Jacobson and others, 2011; Chojnacki and others, 2012; Jacobson and others, 2022).
- Prioritization and design of setbacks also depends on objectives. Whereas setbacks are likely to provide local water-surface elevation decreases during floods, it is less likely that they would provide significant attenuation during large, less-frequent floods. Using the L-536 setback as an example, the 405 hectares added to connected floodplain would amount to less than 0.02% of the volume of the 2019 flood. If significant flood attenuation is a design objective, substantial effort would be needed to evaluate how much connected floodplain would accomplish the objective.

Conclusions—common ground?

The Missouri River has a history of destructive floods. Trends in hydrologic records and predictions from climate-change models indicate potential for increased flooding hazard in the future, as well as increased hydrologic variability. In this context, questions have arisen about the possible roles of naturalized, conservation lands in mitigating flood risk and hazard.

The current state of understanding supports the idea that conservation lands can lower local flood stages, subject to land uses that minimize hydraulic roughness and floodplain sedimentation. Apart from smaller, more frequent floods, flood attenuation is less likely. The long-term geomorphic adjustment of the Missouri River has resulted in longitudinal zones of channel incision and aggradation that have varying potential for floodplain connection. Understanding the longitudinal zonation of connectivity potential may aid in planning for where setbacks and land conversions will be most effective in decreasing flood hazard and increasing ecosystem services. Conversions of productive agricultural lands to conservation entails tradeoffs, including substantial costs in levee setbacks and land acquisition and loss of revenue. In considering costs and benefits of floodplain land conversions, a full accounting of ecosystem service benefits—flood risk reduction, nutrient processing, recreation benefits, etc.—may contribute to defining common ground between flood-risk reduction and conservation.

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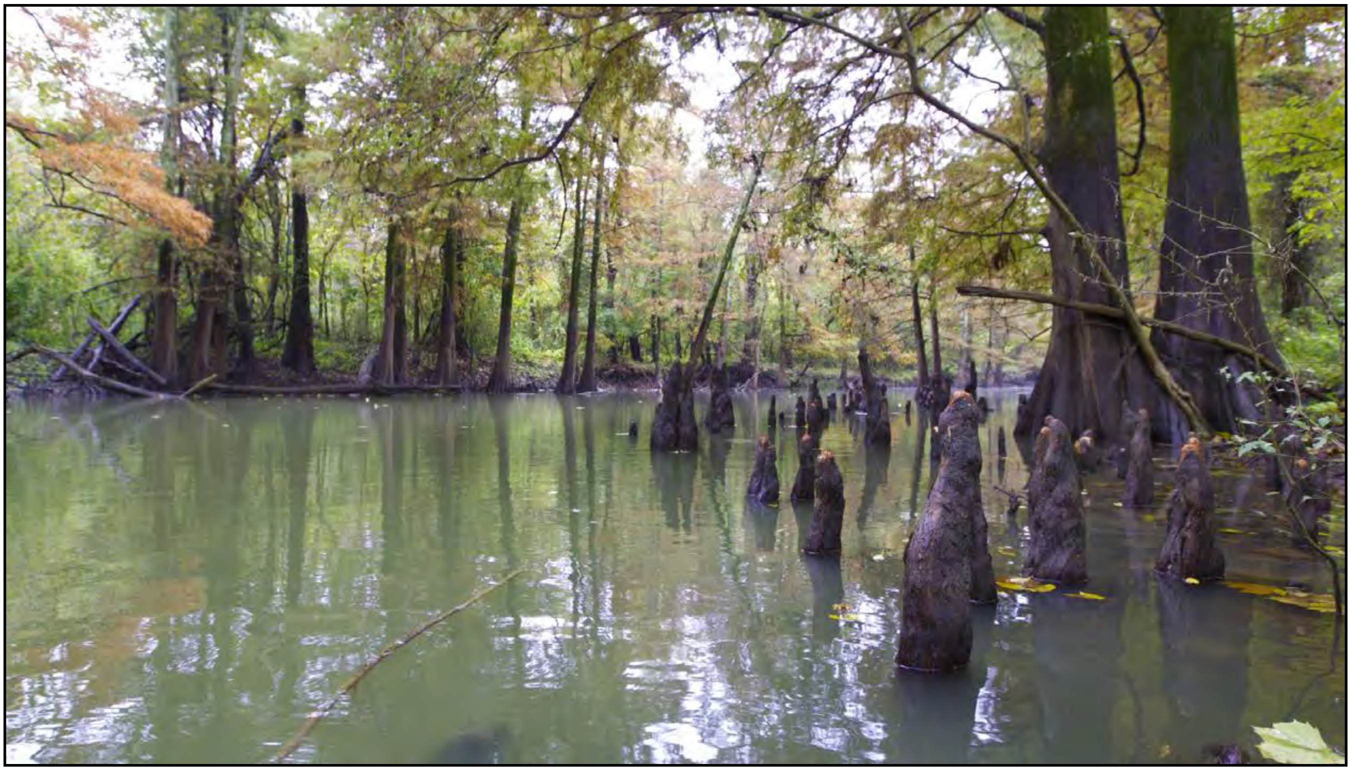


Photo by Jim Rathert, Missouri Department of Conservation

Wolf Bayou NA supports fish and alligator snapping turtle populations, as well as bald cypress trees.

Natural Gems along the Big Muddy and the Father of Waters

by Mike Leahy

Although highly altered, the floodplains of the Missouri and Mississippi Rivers harbor some remnants of wetland natural communities, including a few that are designated Missouri Natural Areas. Here we will take a tour of these natural areas beginning in the northwest corner of the state and ending in the southeast corner.

Missouri River sites

BLUEJOINT-SLOUGHGRASS RESEARCH NATURAL AREA
250 acres. Loess Bluffs National Wildlife Refuge, Holt County.
U.S. Fish & Wildlife Service.

Although not a designated state natural area, the refuge contains a federally designated research natural area named after two dominant wet bottomland prairie species bluejoint *(Calamagrostis canadensis)* and sloughgrass *(Spartina pectinata)*. Although struggling from an invasion of reed canary grass *(Phalaris arundinacea),* this remnant prairie supports a population of the state endangered prairie massasauga *(Sistrurus tergeminus tergeminus).* Loess Bluffs NWR contains a small remnant of once-extensive bottomland prairies in this stretch of the Missouri River floodplain.

LITTLE BEAN MARSH NATURAL AREA
416 acres. Platte County.
Missouri Department of Conservation.

Historically, Little Bean Marsh was part of an oxbow lake that was connected to the Missouri River in a vast riverine landscape of marshes, oxbows, wet prairies, and bottomland forest. The highly-altered Missouri River of today lacks this historic landscape network, and the once vast complex of wetlands associated with the river are largely gone. Little Bean Marsh Natural Area contains one of the last remnants of this system still present along the Missouri River floodplain. An article about the hydrology and water chemistry of the marsh can be found in the newsletter on page 12.

OUMESSOURIT NATURAL AREA
300 acres. Van Meter State Park, Saline County.
Missouri Department of Natural Resources.

The name Oumessourit (pronounced "oo-meh-soo-ree") is the French word for the indigenous peoples that lived in this region. The natural area includes a marsh remnant in the Missouri River floodplain accessible by a boardwalk. Historically, the Missouri River channel was located where the marsh is today. Over time, the river abandoned this site and an oxbow lake was left and eventually filled with sediments to create the marsh of today. Dominant wetland plants include river bulrush (Bolboschoenus fluviatillis), star duckweed *(Lemna trisulca)* and scattered populations of tufted loosestrife *(Lysimachia thyrsiflora)*.

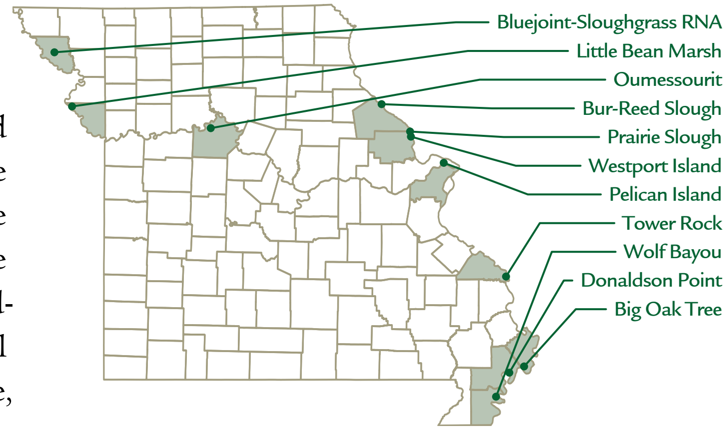
PELICAN ISLAND NATURAL AREA
2,104 acres. St. Louis County.
Missouri Department of Conservation.

This site is recognized as the best remaining example of a mature floodplain forest dominated by large cottonwood trees *(Populus deltoides)* in the Missouri River floodplain. An 1878 map illustrates two islands in the Missouri River that included what is part of Pelican Island today. In 1945, Congress passed an amendment to the 1912 Missouri River Bank Stabilization and Navigation Act which made provisions for a nine-foot deep, three hundred-foot wide channel. Manmade changes to the river since 1945 have indirectly produced the one large island, Pelican Island. Today, the island is comprised of a mix of riverfront forest, slough, shrub-swamp and old-field habitat.

Mississippi River sites:

BUR-REED SLOUGH NATURAL AREA
20 acres. Pike County.
Missouri Department of Conservation.

This small freshwater marsh was one of the areas on the Ted Shanks Conservation Area that was found to contain remnant populations of late successional marsh plants during a 1974 botanical inventory four years after the Missouri Department of Conservation purchased the land. The natural area contains a mix of robust emergent marsh plants such as bur-reed *(Sparganium eurycarpum)*, river bulrush *(Bolboschoenus fluviatilis)* and water smartweed *(Persicaria amphibia)*. Least bitterns *(Ixobrychus exilis)* breed here, and the area provides migratory habitat for Sora rails *(Porzana carolina)*.



Natural areas mentioned in this article.

PRAIRIE SLOUGH NATURAL AREA
406 acres. Lincoln County.
Missouri Department of Conservation.

Prairie Slough, from which the area takes its name, was a chute of the Mississippi River at the turn of the 20th century. The majority of the area was located on the east side of the chute and was an island. Natural river meandering and man's efforts have combined to shift the river flow away from the chute, resulting in a slough, a body of water blocked from the river on the upstream end, except during periods of flooding. The Mississippi River floods of 1993 and 1995 along with hydrologic changes in the river here due to river management have impacted the tree species composition of the area by causing the lower-lying ground to hold more water than the historic condition. Highly flood tolerant species including silver maple *(Acer saccharinum)*, green ash *(Fraxinus pensylvanica)*

and cottonwood *(Populus deltoides)* thrive on the lower ground of this area. Narrow "ridges" in this floodplain support shellbark hickory *(Carya laciniosa)*, pin oak *(Quercus palustris)*, and bur oak *(Quercus macrocarpa)* trees.

WESTPORT ISLAND NATURAL AREA
480 acres. Lincoln County
U.S. Army Corps of Engineers
& Missouri Department of Conservation.

This mature bottomland forest has been impacted by the great floods of 1993 and 1995 but has still retained much of its integrity. The tallest trees in the canopy reach over 100 feet and scattered bur oaks, pecans *(Carya illinoensis),* and sycamores *(Platanus occidentalis)* exceed 30 inches in diameter at 4.5 ft. above the ground. The microtopography of the area possesses flats, short ridges, swales, low terraces and sloughs. This gives rise to a pattern of riverfront forest on the lower elevations (especially along the river), wet bottomland forest and shrub-swamp in the swales and along the sloughs, and wet-mesic bottomland forest on the short ridges and terraces. Green hawthorn *(Crataegus viridis),* a characteristic bottomland forest understory tree, is found here. Swamp privet *(Forestiera acuminata)* found growing around the sloughs is a species found more commonly in the southeast U.S. and here is near the northern limits of its range. In the winter, Bald Eagles are often seen here. During the spring and fall migratory songbirds and waterfowl pass by and through this area. Wood Ducks utilize the sloughs and a heron rookery is present. Barred Owl, Pileated Woodpecker, Red-headed Woodpecker, Northern Parula, and Prothonotary Warbler may be spotted.

TOWER ROCK NATURAL AREA
MDC (PERRY CO.—32 AC)
Missouri Department of Conservation.

Tower Rock is an erosional remnant left as a result of Mississippi River channel shifts. The rock is composed of limestone of the Devonian Period formed some 400 million years ago. Sur-

Photo by Mike Leahy, Missouri Department of Conservation

Mike Arduser stands next to a relic bur oak at Westport Island NA.

Big Oak swamp with yellow flowers: In the spring, Big Oak Tree Natural Area is awash with butterweed (Packera glabella) in the low lying areas that support buttressed bald cypress trees.

rounding softer rocks were eroded away by the Mississippi River leaving the rock which stands about 60 feet above the average river level.

Tower Rock has been the subject of much historical legend and lore. The first written description of this feature was by Father Jacques Marquette from 1673. William Clark mapped the rock in 1803 during their ascent of the Mississippi to begin the exploration of the Missouri River. At the end of the Civil War the U.S. Army Corps of Engineers proposed clearing rocks from the river at this location to eliminate obstacles to navigation. Upon a recommendation of the Secretary of Interior, then president Ulysses Grant issued an executive order on March 4, 1871 which spared Tower Rock from blasting. South of Cairo, Illinois, the Ohio River merges with the Mississippi River and the river's average discharge significantly increases.

BIG OAK TREE NATURAL AREA
940 acres. Mississippi county
Missouri Department of Natural Resources.

A remnant of the vast bottomland forests and swamps that once covered the Mississippi Lowlands region of Missouri can be found at

Big Oak Tree State Park. The natural area and state park stand out in stark contrast to the miles of drained row crop lands surrounding them. In floodplains, the timing, frequency, and duration of flooding and soil saturation determine the type of natural community. At Big Oak Tree, one can witness how slight changes in topography and elevation create major changes in the plant and animal communities. Visitors can walk am elevated boardwalk from an infrequently flooded bottomland hardwood forest dominated by oaks, hickories, and sweetgum *(Liquidamber styraciflua)* to a frequently flooded swamp of bald cypress *(Taxodium distichum)* trees while only going down in elevation by three feet. Birdwatchers have documented 195 bird species from the area, including the most common warbler, the bright yellow Prothonotary Warbler that breeds in the shrub swamp each spring. Once known as the Park of Champions for an abundance of state and national champion trees, changes in hydrology and general threats from island biogeography have resulted in a loss of many of these trees. However, the natural area still harbors the state champion persimmon tree *(Diospyros virginiana)* at 132 ft. tall. The bottomland hardwood tree canopy is diverse with many southeastern tree associations represented such as overcup oak *(Quercus lyrata)* in the lower reaches of the park, and swamp chestnut oak *(Quercus michauxii)* and bur oak *(Quercus macrocarpa)* in the higher elevations.

DONALDSON POINT NATURAL AREA

2,156 acres. New Madrid County.
Missouri Department of Conservation.

Donaldson Point is an enormous bend in the Mississippi River and although the terrain is relatively level, low ridges, swales, oxbows and sloughs dot this large block of forest creating soil conditions that support a diverse mix of overstory trees—from pecan to cypress. Mature emergent cottonwood, sycamore, sweetgum and pecan trees are prime nesting locations for Mississippi Kites which are known to nest here. In the winter and spring, the area is often either flooded or water is ponded in low spots. However, the primarily loamy soils here tend to drain more quickly than heavier-textured soils of bottomland forests farther away from the Mississippi River. One can almost imagine Huckleberry Finn and his raft floating down the river in the antebellum period when standing on the shores of the great river that forms the western boundary of the natural area. This forest provides habitat for a number of species of conservation concern more common to the southeastern U.S. such as the swamp rabbit *(Sylvilagus aquaticus)*, southeastern bat *(Myotis austroriparius)* and Rafinesque's big-eared bat *(Corynorhinus rafinesquii)*.

WOLF BAYOU NATURAL AREA

200 Acres. Pemiscot County.
Missouri Department of Conservation.

It is believed that Wolf Bayou was historically part of the main Mississippi River channel. Until the late 19th century, natural lakes such as this were regularly connected to the Mississippi River when the river flooded. Today, with levees and drainage ditches in place, Wolf Bayou is only re-connected to the Mississippi River during large flood events. The connection to the river is important for fish populations that inhabit these natural lakes.

Wolf Bayou supports a population of the alligator snapping turtle (*Macrochelys temminickii),* a species of conservation concern. This fascinating turtle species is nearly completely aquatic and seldom emerges from the water to bask. Only females searching for egg-laying sites are typically seen on land. One alligator snapper caught in nearby Dunklin County in 1994 weighed 128 pounds.

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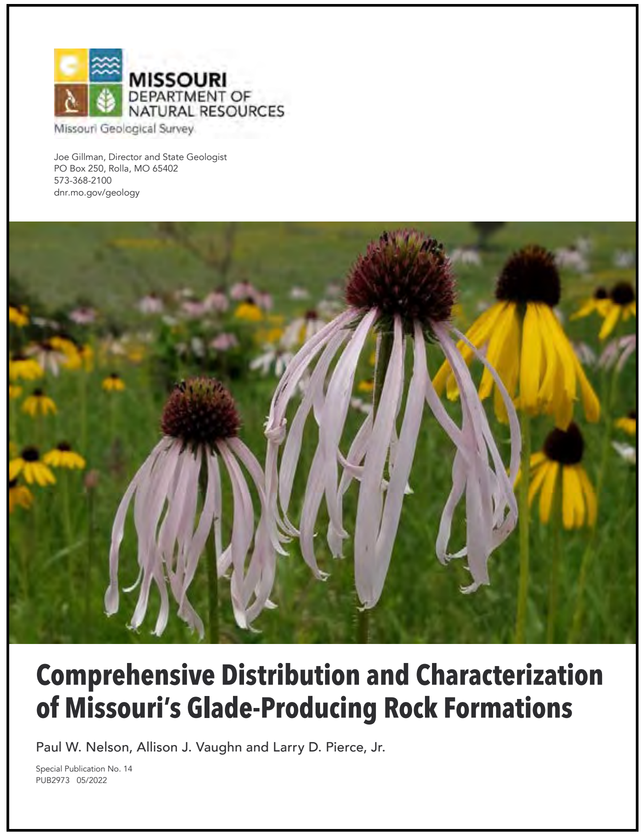
Missouri Department of Natural Resources publishes Report about Glades in Missouri

Below is a MoDNR press release from July, 2022 announcing the publication of a multi-year project to analyze and assign geologic formations to glades mapped in Missouri as a collaboration between the Mark Twain National Forest, Missouri Department of Natural Resources and the Central Hardwoods Joint Venture. All three authors have served on the Missouri Natural Areas Committee in various capacities and terms since 1978. The revised 2018 ArcGIS shapefile, housed on MSDIS, includes in the attribute table the most recent geologic formations published by the Missouri Geological Survey. An earlier open source version of the glade layer that combines Missouri and Arkansas glades, published in 2016, can also be found here: https://databasin.org/datasets/a817fa247dd3440e814282f3063c51d0/. *The MoDNR publication is free to download. Many of the reference condition glade communities in the publication are also Missouri Natural Areas. This publication includes over 58 figures including area glade and geology maps, analysis graphs, and photos.*

The Missouri Department of Natural Resources has released a new comprehensive report about glades in Missouri. The publication, "Comprehensive Distribution and Characterization of Missouri's Glade-Producing Rock Formations," was a collaborative effort between Missouri State Parks Ecologist Allison Vaughn; geologist Larry "Boot" Pierce, Jr., formerly with the department's Missouri Geological Survey; natural community advisor Paul Nelson; and Central Hardwoods Joint Venture.

"This new publication provides insight about glades, where they exist in Missouri and the importance of protecting these special places," said Dru Buntin, director of the Missouri Department of Natural Resources. "Missouri's 182,464 acres of glades are geologically and ecologically unique ecosystems, and this report unveils many previously unknown attributes."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Comprehensive Distribution and Characterization of Missouri's Glade-Producing Rock Formations

Paul W. Nelson, Allison J. Vaughn and Larry D. Pierce, Jr.

Special Publication No. 14
PUB2973 05/2022

Glades are open spaces in woodlands that contain natural rock gardens with unique plants. Their flora, numbering nearly 500 recorded species, along with the many animals that call them home, is of high conservation interest. Glades often lure nature enthusiasts for nature study and enjoyment.

Several Missouri landscapes are known for their glades, including the White River Hills near Branson and the St. Francois Mountains. Most of Missouri's glades are south of the Missouri River, with some located in counties in the Mississippi River hills.

"The geology upon which glades exist is highly variable and is one reason certain plants are found nowhere else," said Vaughn. "Few other Missouri natural communities have attracted as much scientific study as glades."

During the research project, many questions arose once glade patterns and distribution were known. Missouri's complex and varied geology appeared to strongly influence glade distribution, their numbers and patterns. The authors,

with the assistance of field geologists, worked to assign known geologic formations to each glade. This effort resulted in many new revelations about glades, including the discovery that glades occur in locations other than southwest hillsides and the actual acreage of glades is much less than previously thought.

Learn about these discoveries and find more information about Missouri glades in "Comprehensive Distribution and Characterization of Missouri's Glade-Producing Rock Formations," available at https://dnr.mo.gov/document-search/comprehensive-distribution-characterization-missouris-glade-producing-rock-formations-pub2973

MoNAC Newsletter Mailing List

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MISSOURI Natural Areas NEWSLETTER

2022
Volume 22, Number 1

"…identifying, designating, managing and restoring the best remaining examples of natural communities and geological sites encompassing the full spectrum of Missouri's natural heritage"

Editor's Note

Missouri's Big River Systems

The Great Missouri and Mississippi River flood of 1993 remains a seminal event in our state's and the country's history. Beginning in April 1992, above-average rainfall and below-average temperatures resulted in above normal soil moisture and reservoir levels in the Missouri and Mississippi River basins into 1993. In winter 1992–93, the Midwest experienced heavy snowfall, followed by daily one-to-two-inch rains in June and July across northern and central Missouri. Soils in central and northern Missouri were already saturated by June 1. Storms, persistent and repetitive in nature during the late spring and summer, bombarded the Upper Midwest with voluminous rainfall. In one night in July 1993, central Missouri received four to nine inches (locally as high as 18 inches) of rain causing a major river surge in late July. Flood levels topped 20 feet at the levee protecting Chesterfield and Earth City but the levee (built under

A quiet sunset moment on the Missouri River at Boonville.

Photo by Pat Whalen, Missouri Department of Conservation

2023 Event Calendar

February 1–3, 2023

Wetland Summit

Lake of the Ozarks, Missouri

www.confedmo.org/wetlands

February 7, 2023

Oak Woodlands and Forest Fire Consortium Webinar

www.oakfirescience.com/events/webinar-how-is-fire-ecology-different-than-classical-ecology/

February 7–9, 2023

Annual Missouri Natural Resources Conference

Osage Beach, Missouri

www.mnrc.org

February 12–15, 2023

83rd Annual Midwest Fish and Wildlife Conference

Overland Park, Kansas

www.midwestfw.org

March 20–24, 2023

88th North American Wildlife and Natural Resources Conference

St. Louis, Missouri

www.wildlifemanagement.institute/conference

August 23–24, 2023

Annual Missouri Bird Conservation Initiative Conference

Columbia, Missouri

www.mobci.net